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Perception/Action: An Holistic Approach II

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16. Abstract (Limit: 200 words)

This final report reviews three years of research focused on the coordination of perception and action. Human performance has been evaluated within the framework of a closed-loop system where perception and action are intimately coupled. Four problems have been studied: the control of locomotion, dynamic occlusion, depth perception, and minimally invasive surgery. Studies of the control of locomotion have shown that for control of altitude there was an interaction between the flow structure (splay or depression angle) and the event dynamic (hover or forward flight). Results showed that in hover conditions, depression angle specifies altitude changes most reliably; but in forward flight conditions, splay angle specifies altitude changes most reliably. These results are explained as a function of singal-to-noise ratios within the optical flow field. Initial work to evaluate control of collision is also discussed. The dynamic occlusion task was used to evaluate effects of mode of observation (active versus passive) on performance. This task was chosen because of the ability to control for information differences. Results showed that the observation mode had little effect. Previous research that has shown an advantage for active observers appears to be due to information differences, not to the observation mode. Research on depth perception showed that difference that had previously been found for response mode (walking versus matching) could be attributed to the response frame (egocentric versus exocentric). Subjects were generally accurate (little effects due to foreshortening) when using an egocentric response frame. Finally, preliminary work to evaluate performance in minimally invasive surgery is outlined. This work included field observations of surgery as well as laboratory studies to examine the coordination problems involved with remote vision and two-dimensional video displays.

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Abstract

This final report reviews three years of research focused on the coordination of perception and action. Human performance has been evaluated within the framework of a closed-loop system where perception and action are intimately coupled. Four problems have been studied: the control of locomotion, dynamic occlusion, depth perception, and minimally invasive surgery. Studies of the control of locomotion have shown that for control of altitude there was an interaction between the flow structure (splay or depression angle) and the event dynamic (hover or forward flight). Results showed that in hover conditions, depression angle specifies altitude changes most reliably; but in forward flight conditions, splay angle specifies altitude changes most reliably. These results are explained as a function of singal-to-noise ratios within the optical flow field. Initial work to evaluate control of collision is also discussed. The dynamic occlusion task was used to evaluate effects of mode of observation (active versus passive) on performance. This task was chosen because of the ability to control for information differences. Results showed that the observation mode had little effect. Previous research that has shown an advantage for active observers appears to be due to information differences, not to the observation mode. Research on depth perception showed that difference that had previously been found for response mode (walking versus matching) could be attributed to the response frame (egocentric versus exocentric). Subjects were generally accurate (little effects due to foreshortening) when using an egocentric response frame. Finally, preliminary work to evaluate performance in minimally invasive surgery is outlined. This work included field observations of surgery as well as laboratory studies to examine the coordination problems involved with remote vision and two-dimensional video displays.

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condition. However, there is a higher correlation for splay texture when there is signigicant forward motion.

1.0 General Overview

Two strategies that scientists use to reduce the complexity of the natural world are reductionism and abstraction. Reductionism deals with complexity by describing the system in terms of a small number of fundamental elements. In physics the search for fundamental particles and in psychology the search for independent information processing stages or for local neural mechanisms reflect this strategy for attacking complexity. Abstraction deals with complexity by searching for global relational properties that exist somewhat independently of the elements whose behavior they govern. In physics, the idea of "fields" (e.g., gravitational or electro-magnetic) are prototypical examples of the strategy of abstraction. In psychology, the cybernetic hypothesis, that human behavior may be constrained by the same kind of stability constraints as a servomechanism, is an example of abstraction. This is an abstraction in the sense that within a closed-loop system stability is not associated with any particular element of the system. Rather, stability depends on global relations between forward loop gain (sensitivity to error) and time delays. Recent work using nonlinear dynamics to model phase transitions in rhythmic behaviors such as walking also reflect the strategy of abstraction (e.g., Kelso, 1995).

Both reductionism and abstraction have proven value as strategies of science. However, some problems are better approached using one strategy or the other. *A fundamental commitment of our research program is that situation awareness and situated cognition are fundamentally problems of coordination --- in that they address the human operator's capacity to adapt to changing demands and contexts in dynamic environments.* As problems of coordination, we believe that they are best attacked using the strategy of abstraction. While there are a number of obvious and successful examples of how the strategy of abstraction can be used to address problems of human performance, psychology tends to be dominated by reductionist strategies. For this reason, this final report will begin with a brief description of our research framework. This will be followed by descriptions of our experimental programs in four areas: the control of locomotion, dynamic occlusion, distance perception, and minimally invasive surgery.

1.1 General Framework

Although psychologists have greatly expanded how they conceive of stimulus and response, the reductionist strategy depends heavily on stimulus-response (SR) as the fundamental unit of analysis. The experimenter controls the stimulus and measures the subject's responses. In order to achieve control over the stimulus, the experimenter must break all feedback links between the subject's actions and the stimulus. The tachistoscope was an excellent tool for accomplishing this and the computer continues to be used essentially as a tachistoscope in many psychological laboratories studying learning, skill, attention, and perception. The stimuli to be presented and the responses measured are chosen to isolate a particular stage within the human information processing system.

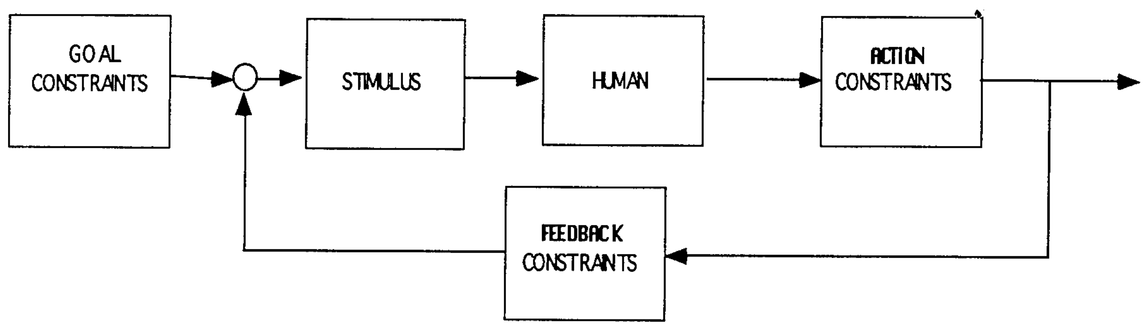

Figure 1. In studying coordination within a closed-loop system the experimenter manipulates goal, action, and feedback constraints, rather than the stimulus. The stimulus at any moment is a function of the responses of the subject.

Since our research focuses on the coordination between perception and action it is not possible to rely exclusively on experimental paradigms that cut the feedback link that supports that coordination. We are forced, in the study of coordination, to relinquish control of the stimulus to our subjects. So how is it possible to do controlled experimental work if you have no control of the stimulus? Figure 1 illustrates how we approach this problem. We manipulate constraints, rather than stimuli. As illustrated in Figure 1, we distinguish 3 general classes of constraints. Constraints on action refer to dynamic constraints that limit the possible responses or movements that are possible within the problem space or work domain. For example, in studying the control of locomotion these constraints might reflect the dynamics of the vehicle and control interface that are provided for the human actor. Constraints on information, refer to the properties of the feedback that are made available to the actor for monitoring progress through the problem space. Again, in the context of control of locomotion, these constraints might reflect the optical properties of dynamic flow fields and/or the display interface that is made available to the human actor. Finally, goal constraints refer to constraints on intention. This includes the value system that determines the costs and benefits associated with the problem space. Again, in the context of the control of locomotion, these constraints might include an explicit track from which the subject is to minimize deviations or instructions with regard to speed and accuracy.

The manipulation of constraints, rather than stimuli, has important implications for the model of causality used to explain phenomenon. The SR approach is based on what Einstein and Infeld (1938) have identified as a mechanistic view of causality. In this view, stimuli and mediating neural mechanisms are seen as the "causes" of responses. The idea of relating responses to constraint, reflects what Einstein and Infeld (1938) refer to as a field view. Einstein and Infeld (1938) explain that where a mechanistic view would describe an interaction in terms of one electrical particle acting on another, "in the new field language it is the description of the field between the two charges, and not the charges themselves, which is essential for an understanding of their action"

(p. 157). In our framework, we consider the action, information, and intentional constraints to be critical components of the "behavioral field". These constraints are not deterministic causes of behavior. Rather, the constraints limit or bound the possibilities for action. *A fundamental goal of our research program is to discover effective ways to represent these behavioral fields so that we can better understand and predict the range of possibilities for action that bound the adaptive relationship between humans and their environments.*

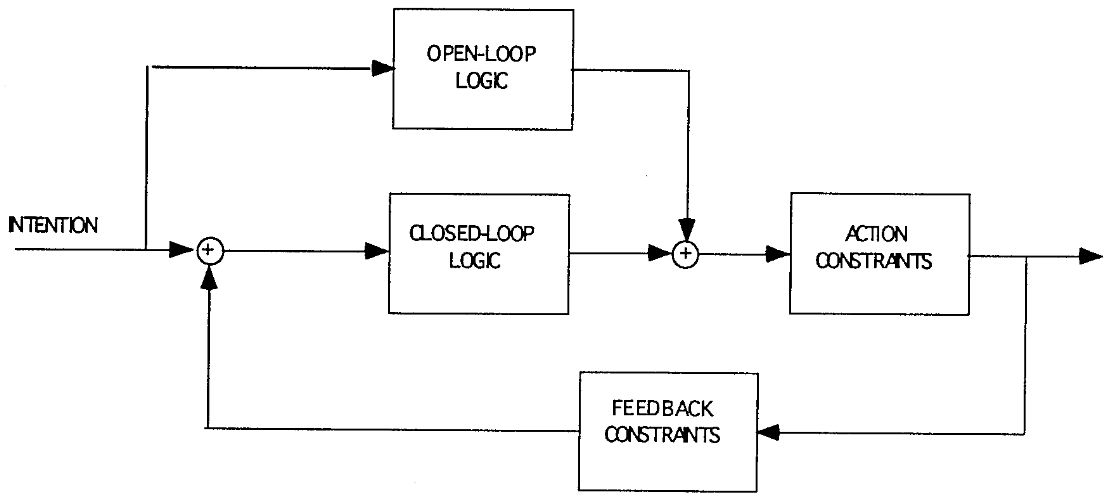

Figure 2. In the pursuit model of control, behavior is jointly determined by open- and closed-loop paths. The open-loop path represents knowledge and expectations. The closed-loop path represents perceptual monitoring of performance.

We have found the language of control theory to be an important tool for visualizing the behavioral field. It is important to note that the use of control theory is not equivalent to the cybernetic hypothesis in which human behavior is modeled in terms of a simple servomechanism (or TOTE unit - Miller, Galanter, & Pribram, 1960). Control theory is a much broader language that includes open- and closed-loop systems as well as adaptive systems. Our basic model for the human controller is what Krendal and McRuer (1960) have called the pursuit mode of control. As shown in Figure 2, the pursuit mode involves both open- and closed-loop paths. The open-loop path reflects the controller's knowledge of the action constraints (e.g., the pilots internal model of the aircraft) and goals (e.g., patterns within the track to be followed). Based on this knowledge (e.g., expectations about the response of the aircraft), the pilot is able to respond directly to an input command (i.e., intention or goal constraint) or to a predictable input pattern and it is not necessary to wait for an error signal. To the extent that the pilot's knowledge is applied appropriately, the response will meet expectations, achieve the goal, and little error will result. However, if the response is not appropriate, then it is still possible for the pilot to make corrections using the error signal in the closed-loop path.

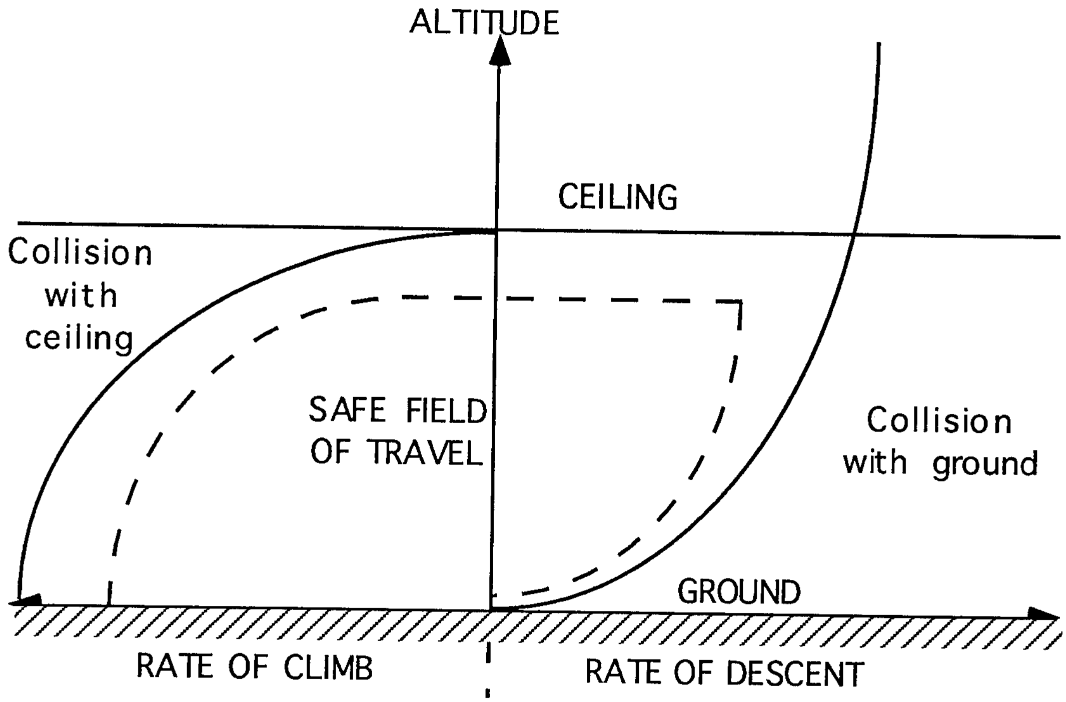

Figure 3. A state space representation illustrating constraints that might bound the safe field of travel for low altitude flight. The ceiling and ground represent goal constraints in terms of specifying negative consequences of collision with the ground or detection by the enemy. The solid parabolic curves represent the 2nd order dynamic constraints on aircraft motion. The dotted parabolic curves represent feedback constraints in terms of the pilot's ability to resolve changes in altitude or velocity.

An important control theoretic representation for illustrating the constraints of a dynamic system is the state space. Flach and Warren (1995) have used the state space to represent the safe field of travel for low altitude flight. Figure 3 is adapted from Flach and Warren. The boundaries in this diagram illustrate some of the constraints for low altitude flight. The ground and ceiling represent goal constraints. That is, these boundaries are associated with negative consequences (i.e., collision with the ground or detection by the enemy). The solid parabolic lines represent action constraints. The shape of this boundary reflects a second-order approximation to the aircraft dynamics. The solid boundary in the right half plane represents the response to a maximum command for lift. This trajectory represents the minimum time path to a soft contact with the ground. Crossing this boundary to the right means that there is no action the pilot can take to avoid a collision with the ground. The dotted lines represent perceptual or feedback constraints. These constraints are approximated as a Weber fraction of the altitude and velocity. That is, the pilot's ability to discriminate a change in altitude or velocity depends on the base value. For example, at higher altitudes the pilot will not be able to resolve small changes in altitude that would be easily discriminable at lower altitudes. Figure

3 is a hypothetical approximation to the constraints that might set the boundaries for safe low altitude flight. Within our framework, *mapping out the actual constraints in a dynamic workspace is an important step to understanding situation awareness and adaptation.*

In the following sections of the report, three task spaces will be described. The first task space is the control of locomotion. This is a work that we have been doing in collaboration with Dr. Rik Warren at the Armstrong Laboratory. For the past few years we have been studying the *active psychophysics* of altitude perception (Flach, 1990; Flach & Warren, 1995a). This research has demonstrated that the ability to control altitude is a joint function of the type of texture (splay angle or depression angle) and the nature of the locomotion (e.g., hover in a rotary wing vehicle versus high velocity forward motion as in a fixed wing vehicle). More recently, this research has focused on collision avoidance. In particular, we have been manipulating flight dynamics and have been testing the extent to which these action constraints are reflected in pilots' control strategies.

The second line of research employed a dynamic occlusion paradigm to compare performance of active and passive observers. The dynamic occlusion paradigm has been chosen as a vehicle for unconfounding the quality of information available from the mode (active versus passive) of the observer. Results from a series of experiments suggests that performance differences result only when there are information differences. When information was equivalent, the mode of observer (active versus passive) had no effect.

A third series of studies examine depth perception as a a function of response mode. Previous experiments had shown that depth judgments depended on the response mode. Passive psychophysical matching tasks resulted in systematic errors such that the extent in depth was increasingly underestimated as the distance from the observer increased. Such a result is consistent with the foreshortening that result due to perspective. However, blind or ballistic walking responses have shown that subjects can accurately walk to targets with little impact of distance. A series of experiments suggested that the response differences were due to the response frame. Subjects were generally accurate when creating distances relative to their own position (egocentric frame). Subjects tended to make errors only when constructing distances relative to arbitrary standards in the environment (exocentric frame).

The final task space is the domain of laparoscopic surgery. For the past year we have been collaborating with Air Force surgeon (Maj. Daniel McKellar, MD at the WPAFB Hospital) to study the decision and perceptual motor demands of laparoscopic surgery. This work has included field observations where we have observed during live surgeries, participant observation where two students and I have been given 4 hours of hands on training in laparoscopic surgery at the Ethicon training facility, and extensive interviews with surgeons. We have also developed a low fidelity simulator for studying perceptual-motor

coordination with video images and laparoscopic instruments. This domain provides an important test of our ability to generalize from our basic research on perceptual-motor coordination to problems of situation awareness in an actual workspace.

2.0 The Control of Locomotion

Detailed reports of our studies on altitude control are contained in two Masters Theses (Kelly, 1993; Garness, 1995) and in a paper that has been excepted for publication, pending revisions in the *Journal of Experimental Psychology: Human Perception & Performance* (Flach, Warren, Garness, Stanard, & Kelly, Under review). The first part of this section will summarize the results of this series of studies. The second part of this section will report on preliminary work directed at control of collisions. The third subsection will describe a prototype for a primary flight display that we are developing. This display utilizes some of the geometrical invariants that we have studied in our research on the control of locomotion.

2.1 Altitude Control

Gibson, Olum, and Rosenblatt (1955) presented one of the first mathematical descriptions of the optical flow field that results from locomotion through a textured environment (in particular, landing an aircraft). From their analysis they concluded that "the motion perspective of a surface like the earth, or a floor or wall, carries information about the direction of one's locomotion (the angle of approach to the surface) as well as a great deal of information about the surface itself" (p. 381). Gibson et al. identified two distinct characteristics of flow in the visual field --- pattern and amount. The radial pattern of flow was identified as a primary source of information for the direction of motion relative to a surface. The gradients of 'amount' of flow were identified as a cue for the perception of distance to the surface. The analysis of the gradients of amount of flow led to the following claims about the information available to the observer (O):

> *O's linear velocity (ground speed) is represented in the optical flow-pattern. Subjective velocity is proportional to the overall velocity of the whole pattern, or to the velocity of any part of it, or to its maximal velocity. The perpendicular distance from O to the surface (altitude) is also represented in the optical flow pattern, and so is distance to the surface on the line of locomotion in the case of a landing glide. Both are inversely proportional to its velocity. Ground-speed and altitude are not, however, independently determined by the optical information. A more rapid flow-pattern may indicate either an increase in speed or a decrease in altitude. Length of time before touching down, however, seems to be given by the optical information in a univocal manner* (p. 382).

It took twenty years until Gibson et al.'s hypothesis, that geometrical properties of the flow field are the basis for control of locomotion, was tested empirically. For example, R. Warren's (1976) evaluation of observer's ability to identify the direction of motion was one of the early empirical studies to test Gibson et al.'s hypotheses. Since that time a number of empirical investigations have attempted to link human performance to various geometrical properties of flow fields (e.g., Cutting, 1986; Cutting, Springer, Braren, & Johnson, 1992; Larish & Flach, 1990; Owen & R. Warren, 1986; Owen, R. Warren, Jensen, Mangold, & Hettinger, 1981; Royden, Banks, & Crowell, 1992; W.H. Warren & Hannon, 1988; 1990; W.H. Warren Mestre, Blackwell, & Morris, 1991; W.H. Warren, Morris, & Kalish, 1988).

The studies presented here continue this program to search for empirical links between geometric properties of flow fields and the control of locomotion. In particular, the focus is on two geometrical properties of flow fields --- splay angle and depression angle---and the role that these properties might play in the regulation of altitude. In the following sections, we first define splay angle and depression angle. Then we review the previous empirical work. Finally, we will report a series of empirical studies to test a hypothesis suggested by Flach, Hagen, and Larish (1991) that has attempted to account for apparently disparate findings in the literature.

2.1.1 Geometric Analysis

The first step in an analysis of the geometric properties of a flow field is to identify the surface texture elements that "carry" the flow. For example, Gibson, et al.'s (1955) analysis assumes points as the texture elements. Denton's (1980) research on judgment of driving speed (edge rate) is an example where the significant texture elements were edges. In the present analysis, the texture elements will be edges. Of course, there is a mapping from points to edges and from edges to points. In fact, it may well be that the distinction between points and edges has far greater implications for the geometrical analysis, than for perception. However, some aspects of flow are more easily visualized and modeled as properties of points, while others are more easily visualized as properties of edges. Splay and depression angle are most easily visualized as properties of edges. Splay angle is a property of edges parallel to the direction of motion. Depression angle is a property of edges perpendicular to the direction of motion.

Splay Angle. *Optical splay angle* was identified as a source of information for altitude by Warren (1982). Warren cites Biggs (1966), who noted that when an observer maintains a constant distance to an edge on the ground plane (e.g., the curb of the road), despite shifting optical positions of the individual points composing the edge, the optical position of the edge was invariant. For an edge parallel to the direction of motion, the invariant optical position can be defined in terms of the angle at the vanishing point formed by the edge and a reference line

perpendicular to the horizon along the ground trace of forward motion, as shown in Figure 4. This angle is defined by the equation:

$$S = \tan^{-1}\left(\frac{Y_g}{z}\right)$$

where **S** is the splay angle, Y_g is the lateral displacement of the line from the perpendicular, and **z** is the altitude (eyeheight) of the observer. The equation describes the projection of the ground texture onto the frontal plane for an observer moving parallel to the ground. For rectilinear motion over a flat ground plane, splay angle is constant when altitude is constant.

The rate of change in splay angle with respect to change in observer position is specified by the following equation (dotted variables are used to specify temporal derivatives):

$$\dot{S} = \left(-\frac{\dot{z}}{z}\right)\cos S \sin S + \left(\frac{\dot{Y}_g}{z}\right)\cos^2 S.$$

The first term [$\left(-\frac{\dot{z}}{z}\right)\cos S \sin S$] indexes change in splay as a function of changes in altitude [$\dot{z}$]. The negative sign indicates that as altitude decreases, splay angle increases, and vice versa. The term [$-\frac{\dot{z}}{z}$] specifies fractional change in altitude or change in altitude scaled in eyeheights. This term indicates that the relation between change in altitude and change in splay angle depends on the initial altitude. At high altitudes (large z), any given change in altitude would result in a smaller change in splay angle than when initial altitude was lower. As noted by Warren (1988), "sensitivity of the display [optical splay rate] varies inversely with altitude: the lower the altitude, the more change in visual effect for equivalent altitude change commands. At very low altitudes this optical activity is dramatic even *optically violent*" (p. A121). The [$-\frac{\dot{z}}{z}$] term is independent of optical position of an edge. It scales the rate of change for every edge in the field of view. For this reason, it has been termed "global perspectival splay rate" (Wolpert, 1987). The sine and cosine terms index the dependence of splay rate on optical position of each edge. Figure 5 shows the change of splay for a 5 ft decrease in altitude from an initial observation height of 25 ft. as a function of the initial splay angle. For edges with 0° splay angle (perpendicular to horizon at the expansion point) and $\pm 90^{\circ}$ splay angle (the horizon), the rate of change will be zero. From these minima, the absolute change in splay angle for a given fractional change in altitude will increase to a maximum at a splay angle of $\pm 45^{\circ}$.

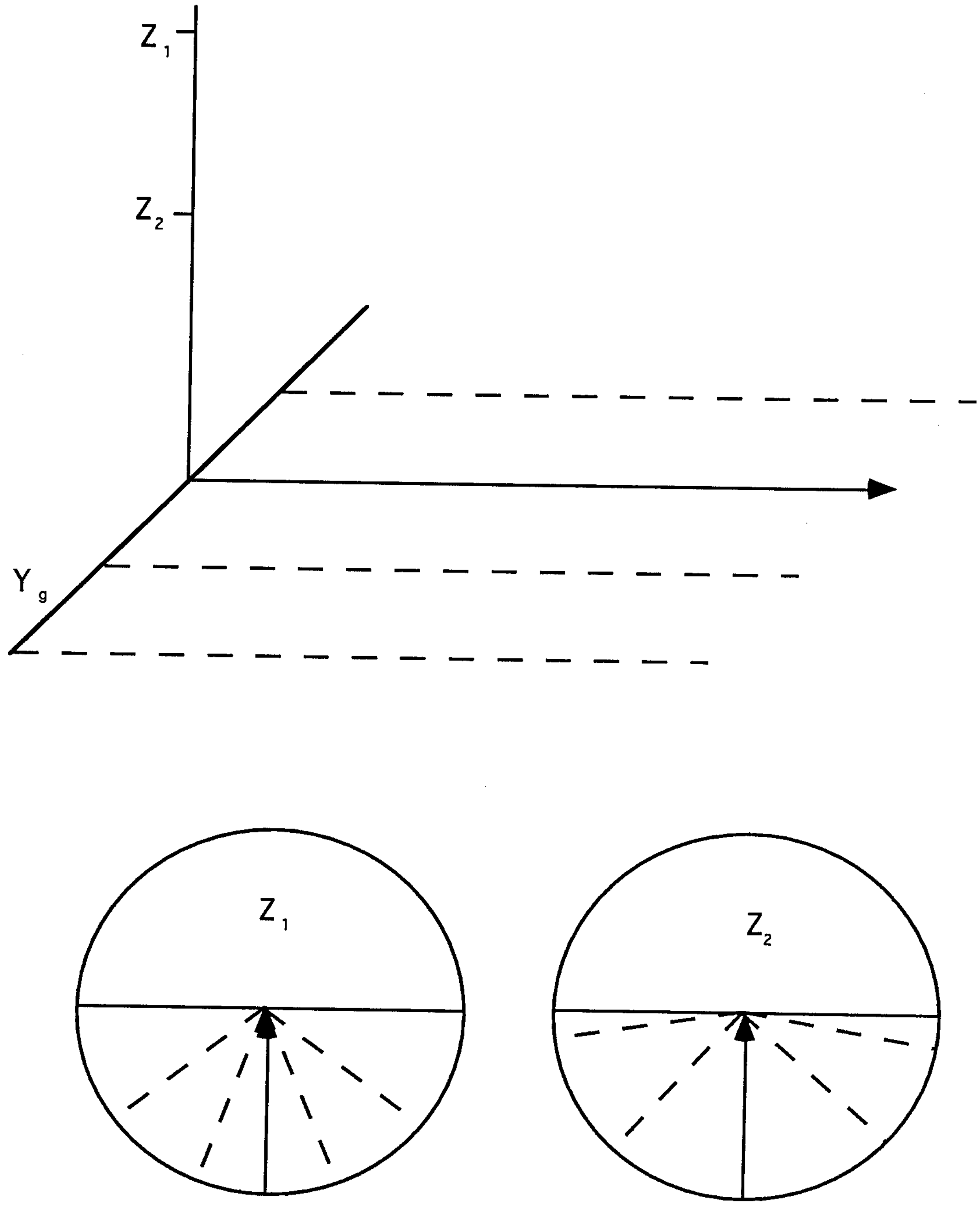

Figure 4. An illustration of the relation between splay angle and altitude. As altitude decreases from Z_1 to Z_2 the splay angle increases.

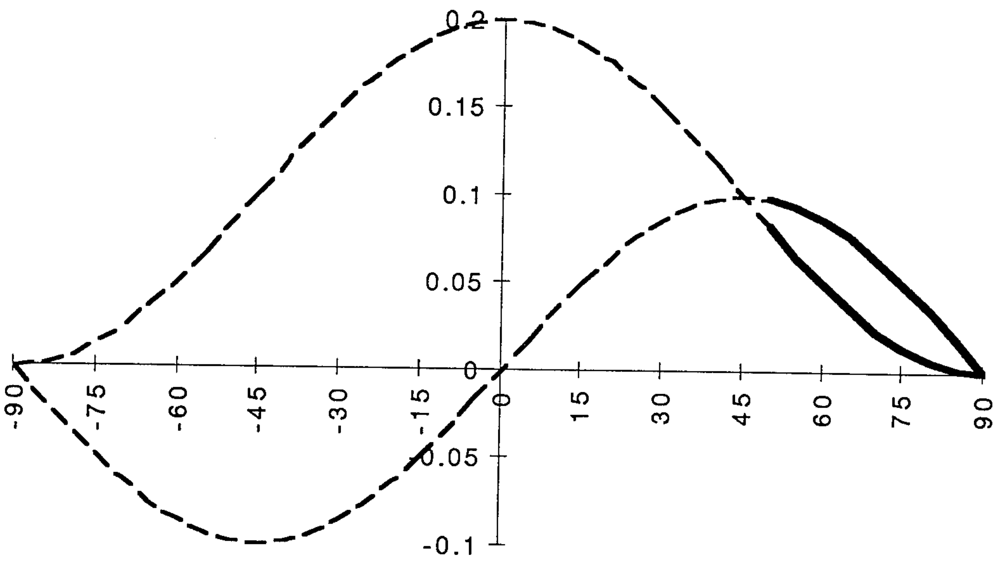

Figure 5. The change of splay or depression angle for a 5 ft decrease in altitude from an initial altitude of 25 ft as a fucntion of the initial angular position is illustrated as a sine function with peaks at ±45°. The change of splay and depression angle as a function of a 5 ft fore-aft or lateral displacement is illustrated as a $\cos^2$ function with peak at 0°. The full range of initial splay anles is typically visible in the frontal field of view. However, alll initial depression angles are not visibel. For the field of view simulated in our experiments initial depression angles below 51.87° were outside of the field of view.

The second term in the equation for change in splay angle [$\left(\frac{\dot{Y}_g}{z}\right)\cos^2 S$] indexes change in lateral distance [$\dot{Y}_g$] from the observer to the edge such as might result from a lateral movement of the observer. For straight ahead forward motion there is no change in lateral distance and this term has no impact on the optical splay angle. For this reason, this term has not typically been included in analyses of splay. However, lateral displacements have sometimes been included in the events that have been simulated to study altitude control. Thus, it is important to understand the effects from this term. The first half of the term [$\frac{\dot{Y}_g}{z}$] specifies lateral displacement rate scaled in eyeheights. Changes in lateral distance result in proportional changes in splay angle. The second half of the term [$\cos^2 S$] indicates how change in splay angle varies as a function of the optical position of a particular line element. Figure 5 illustrates the change in splay angle as a function of initial position for a lateral change of -5 ft. at an altitude of 25 ft. As can be seen in Figure 5, change in splay decreases from a maximum for the texture line directly below the observer (S=0°) to a minimum at the horizon (S=±90°). It is important to note that whereas changes in altitude have symmetrical effects on edges spaced equal distances to each side of the

observer, lateral motions cause a reduction in splay angle for edges in the direction of the lateral motion (negative splay angles become less negative for movement in a negative (left) direction) and an increase in splay angle for edges in the opposite direction from the lateral motion (positive splay angles become more positive). Thus, changes in altitude result in changes in splay angle that are symmetric around the motion path, whereas changes in lateral position have asymmetric effects.

Depression angle. *Optical depression angle* provides yet another potential source of information for changing altitude. Optical depression angle [δ] has been defined as the angular position below the horizon of an edge perpendicular to the direction of motion (Flach, Hagen, & Larish, 1992). However, to make the angles comparable to those used for splay angle, we use the convention of measuring optical depression angle from the point directly below the observer as illustrated in Figure 6. The benefit of this convention is that splay and depression angle are both referenced to the observer, whereas with the older convention splay angle was indexed to the observer and depression angle was indexed to the horizon. This angle can be expressed as a function of altitude (z) and the principal distance on the ground from the observer to the texture element [x_g]:

$$\delta = \tan^{-1}\left(\frac{x_g}{z}\right)$$

For rectilinear motion over a flat ground plane, the rate of change of the optical depression angle will be:

$$\dot{\delta} = -\left(\frac{\dot{z}}{z}\right)\cos\delta\sin\delta + \left(\frac{\dot{x}_g}{z}\right)\cos^2\delta$$

The first term [$-\left(\frac{\dot{z}}{z}\right)\cos\delta\sin\delta$] shows the contribution of changes in the observer's altitude on the optical depression angle. The relation between depression angle and altitude is qualitatively identical to the relation between splay angle and altitude. As with splay angle, the rate of change in depression angle scales with fractional changes in altitude. Also, as with splay angle, the rate of change of depression angle will depend on the initial optical position of a texture element. Rate of change of depression angle will be zero at depression angles of 0° (directly below the observer) and 90° (the frontal horizon) and will be maximum at a depression angle of 45°. This function is identical to the function for splay shown in Figure 5. However, splay angles over the range from -90° to $+90^{\circ}$ are all visible in the frontal field of view, for depression angle only 0° to $+90^{\circ}$ is visible in the frontal field of view (from 0 to -90° is behind the observer). In many practical situations an even smaller range of depression angles will be available due to limits in the frontal field of view (e.g., occlusion due to the bottom edge of a display or window). The solid segment in Figure 5

shows the range of depression angles visible for the viewing conditions used in our studies.

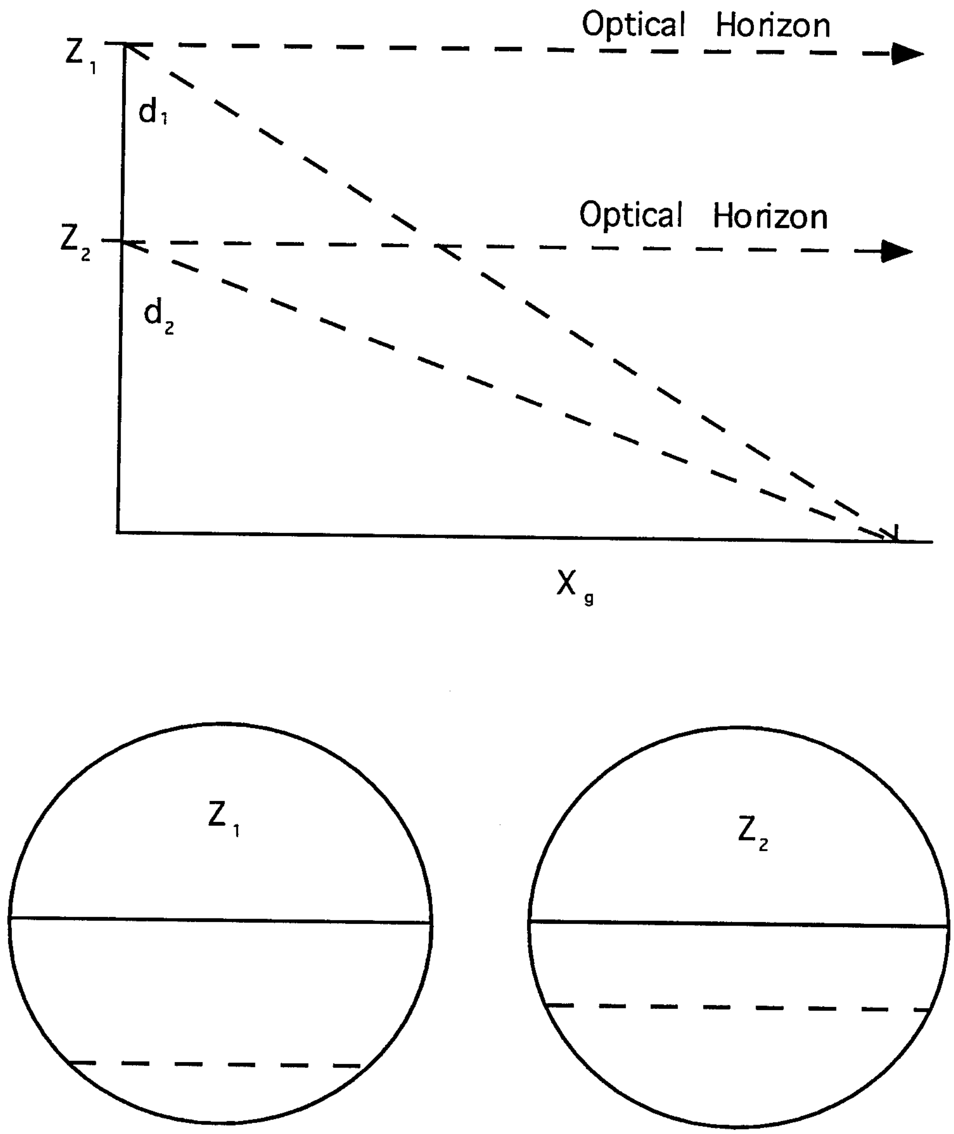

Figure 6. Texture lines perpendicular to the forward path of travel provide information for change in altitude in terms of depression angle. As the observer moves from a high altitude (Z_1) to a lower altitude (Z_2) the depression angle becomes larger and the texture lines move up in the field of view toward the horizon.

The second term in the equation for rate of change of depression angle $[\left(\frac{\dot{x}_g}{z}\right)\cos^2\delta]$ indexes changes in depression angle as a result of forward motion of the observer. In the first part of this term, $\dot{x}_g$ is proportional to the speed of the observer. The term $[\left(\frac{\dot{x}_g}{z}\right)]$ is speed scaled in eyeheights. This term has been

identified as global optical flow rate (Warren, 1982). Thus, the rate at which depression angle changes is affected by both altitude and speed. The remaining part of this term [$\cos^2 \delta$] accounts for changes in depression angle rate due to initial optical position of a texture element. Rate of change of depression angle due to forward motion will be minimum at the horizon (90°) and will increase to a maximum (i.e., exactly $\frac{\dot{x}_g}{z}$) at a point directly below the observer (0°). This can be seen in Figure 5 where the effects for a 5 ft backward motion are shown for an altitude of 25 ft. Thus, the lower the texture element is in the forward field of view, the greater will be the rate of change in depression angle for a given speed of observer movement. Remember, however, that much of the forward field is occluded so that only a subset of the curve (indicated by solid line) will normally be visible.

Both splay angle and depression angle are components of an expansion of texture that is associated with approach to a surface. Lee (1976, 1980) has shown that this expansion pattern may provide important information for control of locomotion in terms of tau or time-to-contact. Lee's analysis reflects Gibson et al.'s (1955) observation that while altitude and speed are not specified unambiguously time before touching down is given in a "univocal manner." It is important to note that while speed and altitude are ambiguous for the flow of dots (global optical flow) and for the flow of horizontal edges (change in depression angle), change of splay specifies change in altitude independent of forward speed. This point will be critical to our hypothesis for predicting an interaction between texture (depression/perpendicular to line of motion versus splay/parallel to the line of motion edges) and forward speed for the perception and control of altitude.

2.1.2 Human Performance

Wolpert, Owen, and Warren (1983) compared observers' ability to detect loss in altitude in a simulation of flight with constant forward speed using three types of texture, as shown in Figure 7: splay (parallel, vertical, or meridian) texture, depression (perpendicular, horizontal, or lateral) texture, and grid (square or checkerboard) texture. Splay texture was chosen to isolate the information available from optical splay, and depression texture was chosen to isolate the information available from global optical density. The results indicated that observers were best able to detect loss in altitude with splay texture. Performance was nominally worse with grid texture and was significantly worse with depression texture. A number of similar studies are summarized by Wolpert (1983, 1987; Wolpert & Owen, 1985). Wolpert (1987) notes that in these studies "loss of altitude scaled in eyeheights proved to be the functional variable, performance improving over increasing levels of that variable. In contrast, ground-unit-scaled loss in altitude showed a minimal effect over the different levels" (p. 24). Because the rate of change of optical splay is

directly related to change of altitude scaled in eyeheights $[-\frac{\dot{z}}{z}]$, whereas optical density is related to change in altitude scaled in ground units, splay was nominated as the effective source of information for judging change in altitude. At that time, no analysis of depression angle had been made. This conclusion must be reconsidered in the light of the analysis of change in depression angle which shows that change of visual angle in the depression texture also scales with fractional change in altitude.

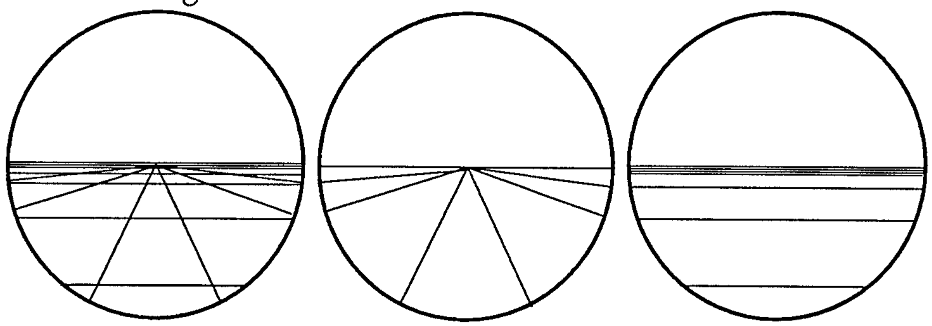

Figure 7. Three types of ground textures that have been used to isolate the components of optic flow associated with change of altitude.

Johnson, Tsang, Bennett, and Phatak (1989) employed a strategy similar to that used by Wolpert et al. (1983) to isolate the optical information available for control of altitude. They used three texture types, splay texture only, which isolates optical splay; depression texture (with a single meridian line roadway to indicate flight path), which was intended to isolate optical depression angle; and grid texture, which contains both optical splay and optical depression information. Unlike Wolpert et al., who measured performance in a passive psychophysical judgment task, Johnson et al. used an active control task. Johnson et al. introduced disturbances in both the vertical and lateral axes. Subjects were to minimize the effects of the vertical disturbance using a single-axis velocity control. Subjects' control actions had no effect on the lateral disturbance. The lateral (side-to-side) disturbance was introduced to prevent subjects from using local information such as the position of a meridian texture line on the bottom of the display (e.g., distance from the corner of a rectangular display) to control altitude. In apparent contradiction to the results of Wolpert et al., Johnson et al. found superior performance (lower tracking error) with the depression and grid textures. Higher tracking error was found for the splay texture.

A second study by Johnson and his colleagues (Johnson, Bennett, O'Donnell & Phatak, 1988) examined active control of altitude in a hover task. In this task, Johnson et al. included disturbances on three axes: altitude [z], lateral $[\dot{Y}_g]$ (visible only in splay texture), and fore-aft $[x_g]$ (visible only in depression texture). Performance was examined for numerous texture types, four of which

were of particular interest for the present discussion: splay, depression, grid, and dot. The results showed equivalent performance (both in terms of tracking error and correlated control power) for depression, grid, and dot textures. Performance with the splay texture showed greater tracking error and lower correlated control power. Again, this result is in apparent contradiction to the findings of Wolpert et al. (1983).

Two differences between Johnson et al.'s studies and the earlier work of Wolpert et al. were the inclusion of disturbances on axes other than the altitude axis and the use of an active control task. Wolpert (1988) employed an active altitude regulation task with disturbances in altitude and roll (subjects only controlled altitude). Note that a roll disturbance affects the optical activity of both parallel and perpendicular texture, but not the angular relations of splay and depression angle. Wolpert found that "altitude was better maintained over parallel [splay] texture than over square [grid] or perpendicular [depression] texture" (p. 17). Wolpert found that whether or not the roll disturbance was included had no effect on performance.

Flach, Hagen, and Larish (1992) also measured performance in an active control task with disturbances similar to those used by Johnson et al. (1988), except that whereas Johnson used a hover task, Flach et al. used a task with forward velocity so that the fore-aft disturbance, implemented as a variable headwind, affected forward velocity, not position. Flach et al.'s results were consistent with Wolpert's. Performance was best with splay and grid textures --- both of which contain splay information. Performance was poor in the depression texture conditions contrary to Johnson et al.'s results.

Wolpert (1988) also included optical flow rate as a variable in his study. He found a performance decrement for increasing levels of global optical flow rate. This is consistent with previous research by Wolpert and Owen (1985). They used global optical flow rates corresponding to walking speed (1 eyeheight/s) and very low flight (.25 & .5 eyeheights/s) and found that detection of descent over square texture deteriorated with increasing global optical flow rates. This is interesting in light of the optical analysis presented earlier. Optical splay angle is independent of global optical flow rate. However, optical depression angle is dependent on global optical flow rate. Global optical flow rate [$\left(\frac{\dot{x}_g}{z}\right)$] changes as a function of altitude (z). However, changes in global optical flow are not specific to altitude. Global optical flow rate is directly proportional to forward velocity[$\dot{x}_g$] and inversely proportional to altitude. This ambiguity had been previously noted in the optical analysis of Gibson et al. (1955).

It is interesting to note that the global optical flow rates examined by Wolpert (1988) and Flach et al. (1992) were all greater than .25 eyeheights/s.

However, the optical flow rates examined by Johnson et al. (1988;1989) ranged from 0 for the hover task to .25 eyeheights/s. Thus, in the Johnson et al. studies the optical flow rates were lower than in previous studies. Also, in each of the studies discussed above, the texture which isolated the most effective optical information (whether splay or depression angle) always yielded performance that was superior to (though not typically significantly superior to) the texture that combined the two sources of information (grid or dot texture). Wolpert et al. (1983) and Wolpert (1988) found that performance was better with splay texture than with grid texture. Johnson et al. (1988, 1989) found that performance was better with depression texture than with grid or dot textures. Also, R. Warren (1988) found that altitude control was superior with splay-only texture than with splay plus superimposed dot texture. Why does the combination of multiple sources of information result in performance degradation?

Perhaps, the optical activity resulting from forward motion (global optical flow rate) makes it more difficult for the observer to pick-up the the optical activity that specifies changes in altitude. In splay-only textures, global optical flow rate is invisible so that there should be no interference. If the rate of forward motion is slow or altitude is high, then the contribution of global optical flow will be small so that interference will be small. But if global optical flow rate is high and can be seen in the display (perpendicular texture elements or dots are present in the display), then the "noise" created by this optical activity may make it difficult for the observer to disambiguate changes in altitude from changes of fore-aft position.

Table 1 shows optical activity as a function of texture and motion. In the experiments reviewed altitude motion is the "signal" to which observers should be responding. Optical activity from fore-aft or lateral motions is "noise." The hypothesis, posed by Flach, et al. (1992), suggests that differential signal-to-noise ratios across the experiments caused the variations in performance observed. This hypothesis is tested in the following experiments.

2.1. 3 Methodology

The subjects' task was to maintain a constant altitude in the presence of wind gusts disturbances. Disturbances affected motion on three axes --- altitude, fore-aft, and lateral (side-to-side). The subjects could control only altitude. The control was a first-order control where stick displacement commanded the rate of change of altitude. Independent variables included the ground texture and the forward speed. Four ground textures were used splay only (vertical lines), depression angle only (horizontal lines), block (both splay and depression angle), and dot. Forward speed varied between zero (hover condition) and 4 eyeheights/s. Dependent variables included RMS altitude error and the correlation between control power and altitude disturbance power in the frequency domain. Details of the apparatus and methodology are available the thesis and journal publications listed in the introduction to this section.

Table 1: Source of Optical Activity

	SIGNAL	NOISE	
TEXTURE	Altitude	Fore-aft	Lateral
GRID	$-\left(\frac{\dot{z}}{z}\right)\cos S \sin S$ $-\left(\frac{\dot{z}}{z}\right)\cos\delta \sin\delta$	$\left(\frac{\dot{x}_g}{z}\right)\cos^2\delta$	$\left(\frac{\dot{Y}_g}{z}\right)\cos^2 S$
DOT	$-\left(\frac{\dot{z}}{z}\right)\cos S \sin S$ $-\left(\frac{\dot{z}}{z}\right)\cos\delta \sin\delta$	$\left(\frac{\dot{x}_g}{z}\right)\cos^2\delta$	$\left(\frac{\dot{Y}_g}{z}\right)\cos^2 S$
DEPRESSION	$-\left(\frac{\dot{z}}{z}\right)\cos\delta \sin\delta$	$\left(\frac{\dot{x}_g}{z}\right)\cos^2\delta$	
SPLAY	$-\left(\frac{\dot{z}}{z}\right)\cos S \sin S$		$\left(\frac{\dot{Y}_g}{z}\right)\cos^2 S$

2.1.4 Summary of Key Results

The pattern of results across the experiments was generally consistent with the signal-to-noise hypothesis of Flach, et al. (1992). The hypothesis was that performance in the altitude regulation task depended on the ratio of optical activity due to altitude (signal) to the optical activity arising from other sources (noise). Table 1 shows how the four textures effect the signal and noise components of optic flow. The specific prediction derived from this hypothesis was an interaction between texture and forward flow rate (i.e., global optical flow rate) such that control will deteriorate for depression texture with increasing flow rates, but that control would be good and independent of flow rate for splay texture. The reason for this prediction is that the forward flow rate is visible with depression texture and thus is an increasing source of noise (i.e., optical activity unrelated to changes in altitude) with increasing forward speeds. Forward flow is invisible for splay texture, thus no increase in noise results with increased forward flow rate. Such interactions were found in all experiments.

The results of these experiments have important implications for examining the visual system within the framework of ideal observer theory (See

Crowell & Banks, In press). The differential performance found for splay and depression textures seems to reflect differences in the quality of the information (signal-to-noise) ratio and not differential attunement or sensitivity of the visual system to a specific component of the optical expansion pattern (i.e., splay angle or depression angle). Thus, when information is most nearly equivalent for the two components (0 forward flow and equivalent initial angular positions in the field of view) near equivalent performance is observed. This is most clear in Figure 8 which shows similar levels of RMS altitude error for the splay and depression textures for zero forward flow rate and in Figure 9 which shows equivalent levels of correlated control power for splay and depression textures.

While performance is equivalent when the signal-to-noise ratio is similar for the two textures, there are a number of factors that contribute to an information bias in favor of the splay texture. First, as shown in Figure 5 the complete range of splay angles is normally visible in the field of regard, whereas only a limited range of depression angles is normally visible. Also, the range of visible splay elements will normally include the points of maximal absolute optical change (± 45°), whereas this will seldom be the case with depression texture.

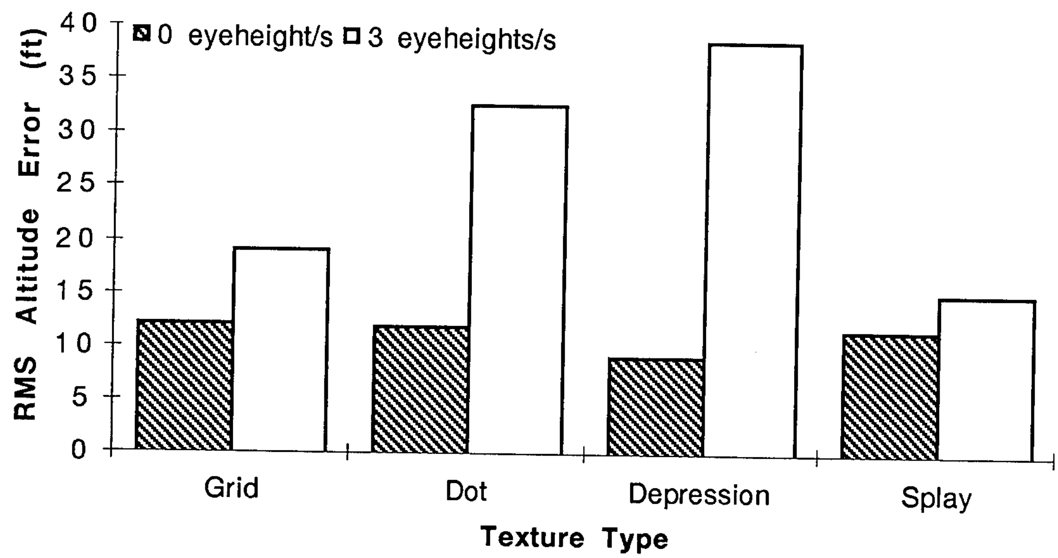

Figure 8. RMS altitude error as a function of texture and forward flow rate. Note that for the hover condidtion less error is seen with depression texture, but with forward motion splay texture results in less error.

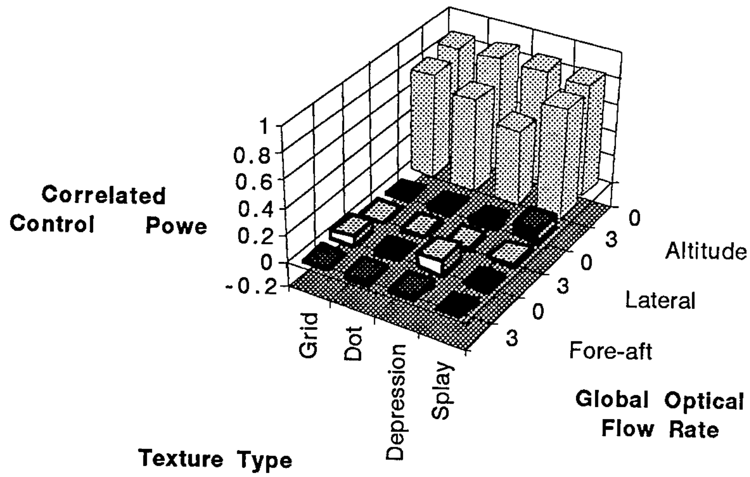

Figure 9. Correlated control power as a function of texture type, disturbance and flow rate. note that the correlations with the altitude disturbance are equivalent for the different textures in the hover condition. However, there is a higher correlation for splay texture when there is signigicant forward motion.

A second factor that contributes to an information bias in favor of the splay texture as information for altitude change is the ubiquitous presence and magnitudes of forward(or fore-aft) motion associated with locomotion. These motions are a source of noise for depression texture, but are not visible in splay texture. Whenever, significant forward motion is present there is a decline in the ability to regulate altitude with depression texture. No such decline is evident for splay texture.

A final factor that contributes to an information bias in favor of splay texture is a distinction in the symmetry of effects due to lateral motion and altitude change on splay angle. Changes in altitude have symmetric effects on splay angle. That is a change in altitude has equal and opposite effects for splay textures equal distances from the right and left of the forward motion path. Lateral motion has an asymmetric effect on splay angle. Splay angle decreases for texture elements in the direction of the motion and increases for texture elements in the opposite direction of the motion. Similar differences in symmetry are also present for depression angle, however, due to limits in the field of view, these asymmetries in depression angle are generally not visible. The difference in symmetry that is visible for splay is information that observers can use to disambiguate optical activity associated with change in altitude from optical activity associated with lateral motion.

There is an important caveat with regard to the optimal observer frame work and the signal-to-noise hypothesis used here. Generally, the "noise" in the optimal observer framework reflects resolution of the visual processing system (e.g., different resolutions of the central and peripheral retina --- Crowell and Banks, In press). However, in the context of our experiments, the distinctions

between signal and noise arise from the specific experimental task used. Optical changes arising from forward or lateral motion are only "noise" relative to the goal of discriminating changes in altitude. A strong case could be made that this task is not representative of natural locomotion. In natural locomotion, all disturbances (altitude, fore-aft, and lateral) are important signals. In fact, it might be further argued that higher order relational properties of these components are the true signals that guide locomotion. For example, with a fixed wing aircraft altitude depends on air speed. Increased airspeed results in increased lift (a gain in altitude), reduced airspeed results in reduction in lift (a decrease in altitude). Thus, we should be very careful in generalizing the results from the experiments reported here to the general problem of control of locomotion. This caveat applies equally well to all the studies on altitude control that have been reviewed in the introduction.

A second caveat, concerns the use of the term "noise" to characterize the optical effects due to movements in axes other than the vertical axis. Two types of disturbances were used. One type of disturbance was a sum-of sines disturbance. This disturbance was applied to both the for-aft and lateral axes. In zero forward flow conditions this was the only type of "noise" present. This was "noise" in the sense that the effects were variable and not easily predicted by the actor. The other type of disturbance was that due to the forward flow rate. This was "noise" in the sense that the optical effects were irrelevant to the problem of controlling altitude. However, the effects of forward flow rate were constant within a trial. It has been suggested by Walt Johnson (personal communication) that the effect of flow rate might be better understood in the context of a Weber fraction. That is, the ability to see changes in the optical activity (i.e., due to change in altitude) may depend on the base level of optical activity. In this sense, global optical flow rate is not noise in the sense of being an unpredictable or quasi-random disturbance. Rather it establishes the base line from which observers are sensitive to fractional changes. Thus, with increasing flow rate proportionally greater changes in altitude are required to yield the same perceptual effect.

A third caveat concerns the notion of "equating information." Splay and depression angles are qualitatively different kinds of angles as they "appear" in the visual field of view. Thus, equating them in terms of optical rates of change does not necessarily mean that they are psychophysically equivalent. It will be important to test the psychophysical equivalence of these two sources of information directly. A psychophysical program is needed to evaluate the relative sensitivities to the various optical changes.

To end the discussion, we raise a final puzzle for future research. In terms of disambiguating optical changes in depression angle due to change in altitude from those due to change in fore-aft position (e.g., global optical flow rate) what is the ideal field of view? Or what is the ideal field of regard --- where should the observer look, out toward the horizon or further down in the field of view? The

maximum change in depression angle for a given change in altitude will occur at 45°. Will performance improve when this peak is included in the field of view? Early on we would have said yes to this question. This thinking was part of the rationale for equating the textures (splay and depression angle) for peak rates of change in Experiment 2. However, discussions with Walt Johnson have caused us to reasses our position. Figure 10 illustrates the puzzle. Figure 10 shows the components of optical change in a forward field of view including 50° below the horizon. The dotted line shows optical change due to a 5ft. change in altitude from a height of 25 ft. The solid line shows absolute optical change due to movement forward at one eyeheight per second (25 ft/s at 25 ft.). Note that a crossover occurs at an angle 78.7° degrees. Below this crossover changes due to forward flow are larger than changes due to altitude. Above this crossover the opposite is true. Perhaps relative change is the critical factor determining sensitivity. Thus, the observer should look near the horizon where rates of change due to altitude are relatively large compared to rates of change due to forward motion. If it is the relative change that is critical, then does discriminability depend on the relative peaks within the field of regard or on an integral function over the two curves (e.g., the average change over the field of regard).

If relative change is the critical variable for discriminating altitude change from forward flow, then the crossover point seen in Figure 10 is critical. The crossover point can be computed by equating the formulas for the two components of optical change and solving for the angle:

$$-\left(\frac{\dot{z}}{z}\right)\cos\delta\sin\delta = \left(\frac{\dot{x}_g}{z}\right)\cos^2\delta$$

$$\delta = \tan^{-1}\left(\frac{\dot{x}_g}{\dot{z}}\right)$$

The crossover point is a tangent function of the ratio of forward speed to rate of change of altitude. In Figure 10, the forward flow rate was five times faster than the rate for change in altitude. If the average change in altitude was equal to the average flow rate (i.e. $\delta = \tan^{-1} 1$), then the crossover point would be at 45° as shown in Figure 5 and the maximum advantage for altitude change relative to forward motion occurs at about 67.5°. Important psychophysical questions remain about how field of regard, field of view, texture, and task dynamics interact to determine optimal strategies for extracting control relevant information from optic flow.

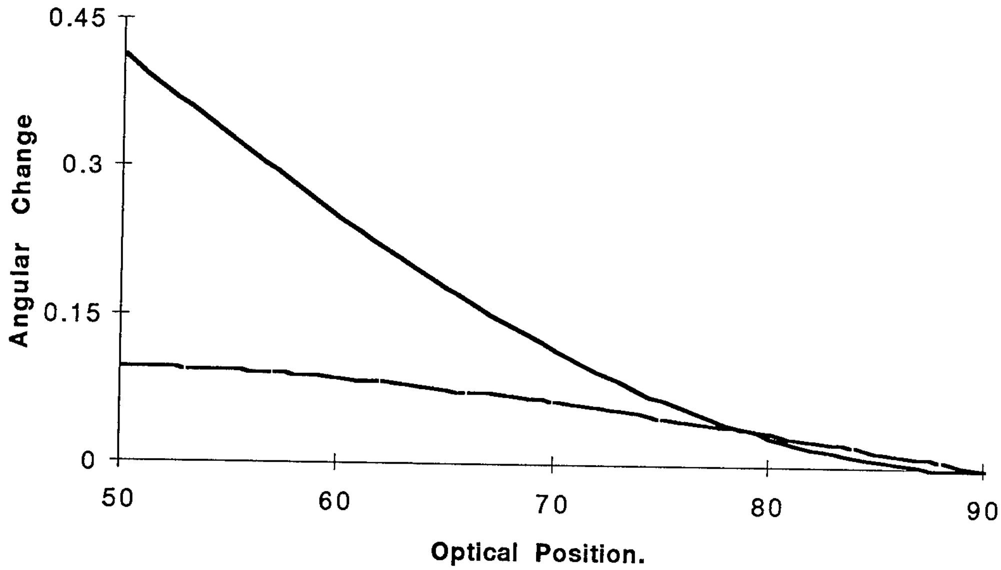

Figure 10. The change in depression angle as a function of optical position for two movements. The dotted line shos optical change due to a 5 ft change in altitude from an altitude of 25 ft. The solid line shows optical change resulting from a 25 ft change (i.e., one eyeheight in fore-aft position.

In conclusion, the performance differences that have in the past been attributed to different textures (splay or depression texture) seem to result from differential rates of optical change specific to altitude change, relative to the rates of optical change resulting from other motions. The visual system does not appear to be differentially tuned to one component of the expansion pattern (splay angle) or the other (depression angle). There appear to be a number of important factors that create a general information bias in favor of splay angle as a more robust and salient source of information for specifying altitude change. However, many psychophysical questions remain to be addressed before we can fully specify the limiting factors for extracting information from optic flow and the implications for the control of locomotion in general and the control of low altitude flight in particular.

2.2 Control of Collision

Recently, we have turned our attention to the problem of collision avoidance. There are several reasons for this. First, we believe that altitude control is best seen as a special case of collision avoidance (avoiding collision with the ground). Second, the problem of collision avoidance brings in the problem of control dynamics. The dynamics of stopping and maneuvering are critical in determining how closely obstacles can be approached without collisions. For example, safe following distance for a car depends on the handling and braking qualities. A loaded truck requires greater braking distances than an empty truck. Thus, studying the control of collisions allows us

to focus on pilots' abilities to perceive the boundaries set by the vehicle dynamics and the interaction of these action constraints with fixed constraints such as the ground.

In a pilot study, we varied the dynamic constraints in a terrain following task as shown in Figure 11. At the start of the task the vehicle was moving toward a cliff at a particular velocity. The subject had a discrete (button switch) control that was used to initiate ascent. The subjects' task was to initiate ascent at the last possible moment so that the vehicle just passed over the edge of the cliff, narrowly avoiding collision. The two critical independent variables were the ascent dynamics and the approach velocity. For half the subjects (Constant Ascent Group) the climb rate was constant, independent of forward velocity. To do the task successfully, this group would have to initiate ascent farther from the cliff face when moving at high velocities than when moving at slower velocities. For the second half of subjects (Proportional Ascent Group) the climb rate was proportional to velocity. That is, at higher velocities the vehicle would climb at a higher rate. The consequence of this dynamic was that the optimum position for initiating the ascent was independent of velocity. The subject could initiate climb at a fixed distance from the cliff independent of the forward velocity. Figure 5 shows the boundaries set by these two dynamics. For the Constant Ascent Group the optimal distance from the cliff increases with increasing velocity. For the Proportional Ascent Group the optimal distance is constant.

Figure 12 shows data from the final block of training. Note that this figure takes the form of a state space diagram. The patterns of data within this state space suggest that the subjects are sensitive to the different action boundaries for the two dynamics. The Constant Ascent Group began ascent at distances that increased with increasing velocity. The slope of this function is very similar to that of the optimum boundary. The Proportional Ascent Group also began ascent at farther distances with increased velocities. However, the slope of this function is much shallower than for the Constant Ascent Group --- approaching the zero slope of the optimal boundary.

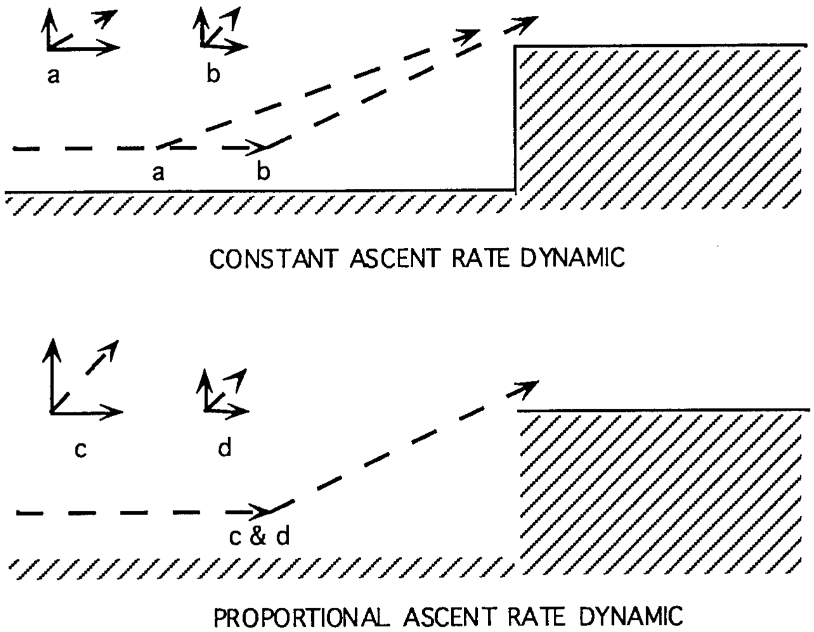

Figure 11. These diagrams illustrate the consequences of the two different dynamic constraints. For the constant ascent rate dynamic, ascent rate is constant. Thus, to just clear the cliff the pilot must initiate the climb farther from the cliff when the forward velocity is greater (a) than when it is lower (b). For the proportional ascent rate dynamic, ascent rate is proportional to forward velocity. The result of this is that the pilot must initiate ascent at the same position, independent of whether forward velocity is high (c) or low (d).

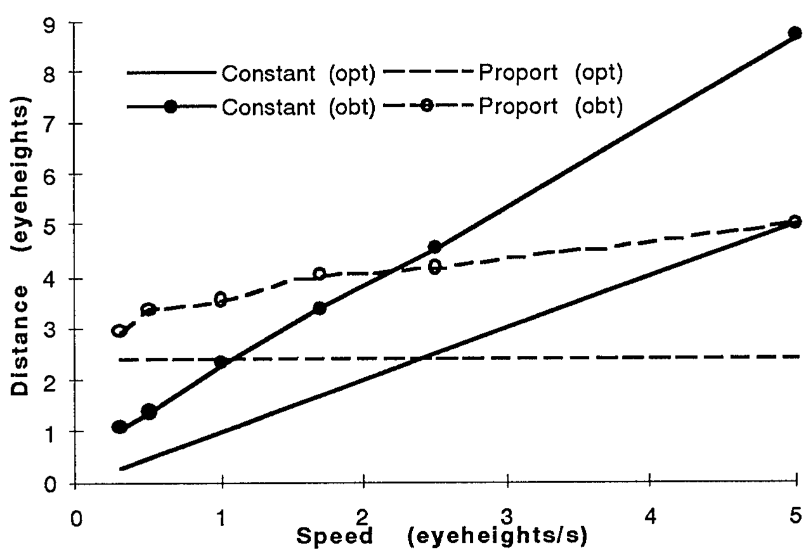

Figure 12. The solid line represents optimal performance for the constant ascent rate dynamic. The dotted line represents *opt*imal performance for the proportional ascent rate dynamic. The filled circles show actual *obt*ained performance for subjects trained with the constant ascent rate dynamic. The open circles show actual performance for subjects trained in the proportional ascent rate dynamic.

The pilot data show that subjects were capable of detecting and adjusting for boundaries defined by their vehicle dynamics. However, the data do not let us infer what structures in the optical flow field specify the dynamic boundaries. The focus of this portion of the research program will be to evaluate the interactions (interrelations) between dynamic constraints and feedback constraints in terms of optical structure in flow fields. The general strategy will be to design experiments where changes in dynamics are crossed with changes in the optical structure of the flow field. Important optical structures that will be manipulated will include edge rate, global optical flow rate, the rate of optical expansion (tau), and local size and distance cues. For example, tau, which is derived from the optical expansion rate of an approaching object, specifies an impending collision in terms of time-to-contact (e.g., Kaiser & Mowafy, 1993; Lee, 1980; Tresilian, 1994). Tau takes into account both speed and distance. Tau could be an important source of information for the constant ascent dynamic conditions. However, because the appropriate response for the proportional ascent dynamic is independent of forward speed, dependence on tau might lead to inappropriate control strategies. An experiment, will cross information for tau (e.g., texture on the cliff face) with other sources of information for approach speed (e.g., edge rate which will vary with spacing of ground texture and global optical flow which will vary with the altitude of the approach trajectory). These information variables will be crossed with the control dynamics. The factorial crossing of the approach dynamic with information for time-to-contact, and information for the speed of self-motion will help us to learn the extent to which the control of collision is based on tau alone or to what extent it is influenced by alternative sources of information for self-motion velocity. The dynamic variable allows us to measure the reliance on tau both when it <u>is</u> and <u>is not</u> an appropriate source of information. If the human visual system has specialized mechanisms for detecting and using tau, then tau's influence might be seen even when the information provided is not optimal for the control dynamics. Indeed, Figure 12 shows some evidence that even with the proportional ascent rate dynamics (where tau is inappropriate) subjects persisted to initiate their ascent at further distances when forward speed was greater. Another way to phrase the question is --- what are the visual primitives that are used in controlling collisions? We know that depending on the control dynamics the correct actions may depend on both position and velocity. However, are position and velocity independently processed by the visual system and then integrated in the decision process or is the perceptual primitive some higher-order variable (such as tau) in which position and velocity are naturally integrated? If this last case is true, then one might expect to see the residual influences of velocity even when the dynamic does not require actions to vary with velocity.

2.3 Configural Attitude Display

As a result of our analysis of the optical invariants that specify self-motion (e.g., Flach & Warren, 1995). We have been developing a prototype for a primary flight display that incorporates key elements of the optical flow field within a

single configural representation. This display which is illustrated in Figure 13. integrates information about pitch, roll, altitude, air speed, and heading into a single perceptual object. Pitch and roll use standard inside-out symbology. Altitude is represented in terms of splay lines. Air speed is represented as flow lines. Heading is represented in terms of a compass which frames the object. Code for a working prototype is being developed. We hope to test this display with air force pilots in facilities at either the Armstrong or Wright Laboratories within the coming year.

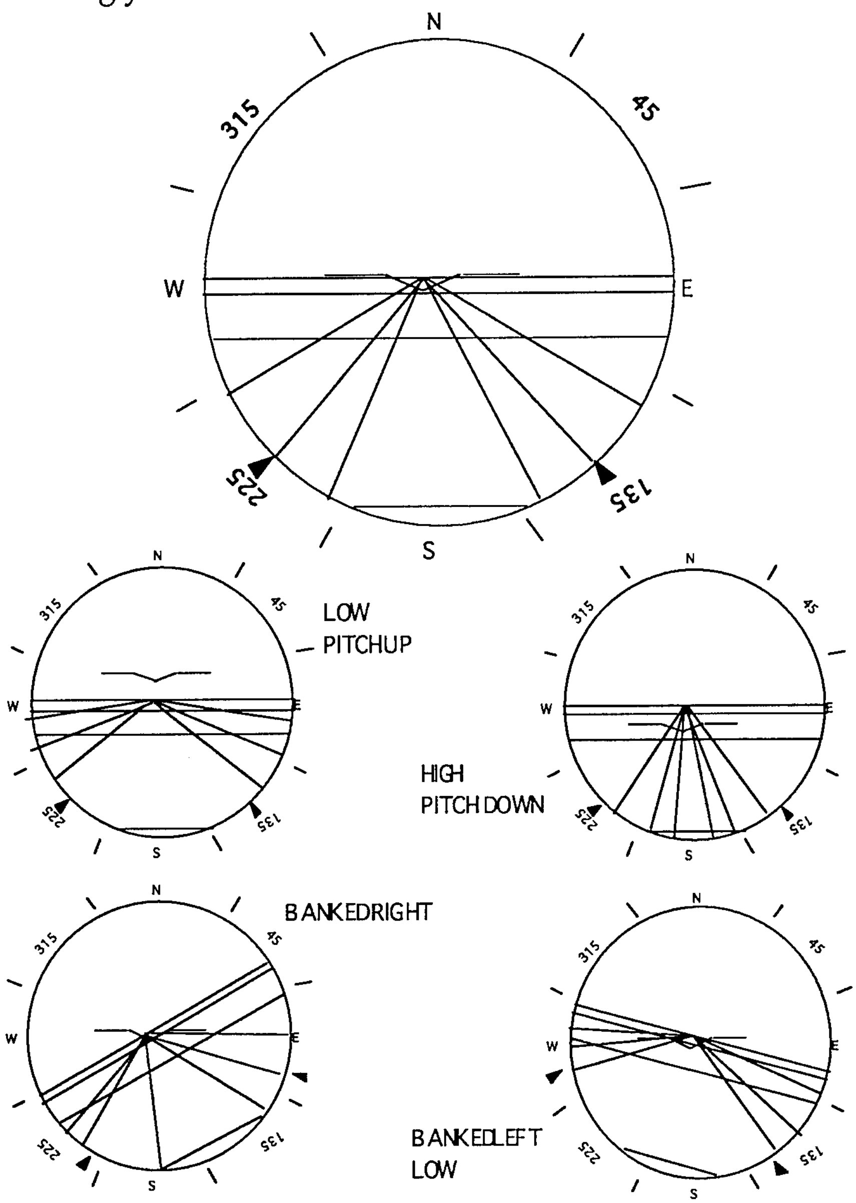

Figure 13. The configural atitude display integrates pitch, roll, altitude, air speed and heading into a single configural representation.

3.0 Dynamic Occlusion

More complete descriptions of this research are available in three Master Theses conducted at Wright State University (Allen, 1993; Brickman, 1994; Hutton, 1993) a paper is also currently under review for publication in the journal *Human Factors* (Flach, Allen, Bell, Brickman, & Hutton, Under review).

One potential problem with increased automation in human-machine systems has been identified by Wickens (1984) as "out-of-the-loop familiarity." That is, if the operator is not actively engaged within a control loop (for example, when the auto pilot is engaged), then s/he will be slower to detect errors and slower to exert the appropriate corrective actions once errors are detected. Wickens cites numerous studies that have found increased detection latency and reduced accuracy, when the operator is not actively controlling the process (Ephrath & Young, 1981; Kessel & Wickens, 1982; Wickens & Kessel, 1979, 1980). Wicken's observation, that there is an advantage for the active observer compared to the passive observer, also is supported by basic research in human performance. This basic research has demonstrated improved performance for active observers in identifying objects by touch (Gibson, 1962) and in developing perceptual motor coordination and in adapting to perceptual distortions (Held, 1965; Held & Bossom, 1961; Held & Freeman, 1963; Held & Hein, 1958; 1963; Held & Shank, 1959).

However, there are also numerous studies that raise questions about what it means to be "in-the-loop" or to be "actively engaged." Bell (1989) reviews several studies that show superior fault detection performance for "auto pilot" conditions (Ephrath & Curry, 1977; Ephrath & Young, 1981, Experiment 2). Bell suggests that many factors including task complexity, attention, workload, information, failure type, and task type may interact with the "mode" of the operator (in or out-of-the-loop or active versus passive) to determine the ultimate quality of performance. Also, basic research has raised questions about the importance of mode relative to other variables. Schwartz, Perey, and Azulay (1975) replicated Gibson's (1962) touch experiment. They found that when care was taken to match the quality of stimulation for active and passive observers the passive observers improved to a level comparable to active observers. Walk, Shepherd, and Miller (1988) replicated Held and Hein's (1963) study of the importance of movement produced stimulation on the development of visually guided behavior. Their results suggested that when differences in attentional engagement between active and passive kittens were controlled, the passive kittens showed no evidence of retarded development as found by Held and Hein. Welch (1986) in an extensive review of the adaptation literature concluded that "it now seems clear that although active perceptual-motor behavior is an ideal condition for the production of adaptation to perceptual rearrangement, it is not a necessary one. Rather, a variety of forms of information (e.g., error-corrective feedback, passive exposure to sharply defined visual-proprioceptive discrepancy) will suffice" (p. 24.37).

Upon reviewing the research on the role of mode (active versus passive) in human performance it becomes clear that it is extremely difficult to separate the effects of mode from other variables. However, understanding the role of mode has important implications for applied and basic human performance theory. For applications, it has important implications for the design and use of automation for vehicular and process control. For basic research, it has important implications for research methodologies. Laboratory research on perception often is designed so that the loop between perception and action is cut. That is, in order that the experimenters have complete control over the "stimuli," perceptual tasks are designed so that the stimulation is completely divorced from the subjects' responses. In these domains the subjects are essentially passive observers who make judgments about stimuli that are imposed by an experimenter. Will performance of these passive observers generalize to situations outside the laboratory where the human is more likely to be actively in control of stimulation? Flach and Warren (Flach, 1990, 1993; Flach & Warren, In press; Warren & McMillan, 1984) have recently argued that an "active psychophysics" is required to extend and test the generality of conclusions based on passive laboratory paradigms.

3.1 Methodology.

To help further understand the role of action in perception, a series of experiments was conducted using a dynamic occlusion paradigm derived from Stappers (1989). The subjects' task was to identify a 3-dimensional wire frame object based on the occlusion and disocclusion of point lights resulting from motion of the otherwise invisible object. The key manipulation was the mode for producing motion of the object. Subjects were tested in yoked pairs. One subject (Active) controlled the motion of the object by manipulating a two-dimensional joy stick control. The second subject (Passive) had no control over object motion, but saw the pattern of motion produced by the active subject. The dynamic occlusion paradigm provides an opportunity to match subjects for information and attentional demands. That is, both subjects saw identical visual displays (i.e., the patterns of occlusion and disocclusion were identical). Also, the identical displays provided a comparable attentional frame and the goal of identifying the object shape was equivalent for both subjects. Using a similar task (with two-dimensional objects), Stappers (1989) provided evidence that there would be an advantage for the active observer. Thus, our hypothesis was that the active observers would be better able to identify the objects than the passive observers. We hoped that the dynamic occlusion task would reveal the contribution of mode unconfounded with differences due to information or attentional factors.

3.2 Results

When we initiated this research program we expected that there would be an advantage for the active subjects in this task. This prediction was not supported by the data. Numerous experiments under a wide range of conditions

showed consistently that there was little difference as a function of Mode when information was equivalent. Our experiments suggest that when attention and information factors were controlled, there was no advantages to being "in-the-loop." This is consistent with studies by Schwartz, Perey, and Azulay (1975) and Walk, Shepherd, and Miller (1988). In those studies, differences previously attributed to mode (Gibson, 1962; Held & Hein, 1963) disappeared when attention and information were equated across conditions.

The results from this study are also consistent with a recent review of research on adaptation to visual rearrangement (Welch, 1986). Held and his colleagues (e.g., Hein & Held, 1962) had argued that active bodily movement was a necessary condition for adaptation to visual rearrangement. However Welch cites numerous studies that have found that "passive bodily movement does lead to a certain amount of adaptation, although frequently less than produced by active movement" (p. 24.10). Howard and Templeton (1966) suggest that the advantages that have been observed for active subjects in many adaptation studies might be due to the salient information about the visual rearrangement that is provided by action. Welch (1986) calls this the "information hypothesis." In other words, it is the information that is critical to performance, not whether that information arises from subject activity or not. Of course, in most situations activity is critical for making information available and for directing the actor's attention. Thus, it is usually the case that constraints on action will, in effect, be constraints on information.

Bell (1989) draws a similar conclusion from the conflicting findings on the benefits of being "in-the-loop" for the detection and recovery from failures in human-machine systems. Bell's analysis suggests that being "in-the-loop" will facilitate detection of failures only when there is information that is only available (or that is more salient) to the pilot who is manually engaged with the system (e.g., proprioceptive feedback).

Of course, great care must be taken in generalizing from the results of this study. First, we are generalizing based on a null result. Obviously, we cannot prove that active and passive subjects are equal. However, the data does suggest that the effects of Mode are small relative to individual differences and relative to other factors such as density and practice. The significant effects of density and practice provide evidence that the failure to find an effect of Mode was not due to simple ceiling or floor effects.

A second concern for generalization is the dynamic occlusion task itself. It is possible that the task of identifying the shape of an object is not representative of the kinds of tasks where self generated action would be necessary. The attributes of the dynamic occlusion task that make it easy to equate active and passive subjects in terms of information and attention may be exactly the attributes that make action unnecessary. For example, the control of self motion may be very different than shape identification. In controlling self motion,

control inputs to limbs or to a vehicle may be critical for determining the response dynamics of the system. Shape identification is a purely kinematic task, there are no dynamics. However, this is not necessarily a threat to the information hypothesis. Action (e.g., pulsing your brakes to test for changes in the braking dynamics due to a change in surface properties due to snow) may be the only path to certain kinds of information. The bottom line then, would be consistent with Howard and Templeton's (1966) conclusion that action is only important to the extent that it differentially affects access to information.

In sum, the results from this study add a small grain of evidence in favor of the "information hypothesis." Information, not mode, is the critical variable ultimately constraining situation awareness. The dynamic occlusion task is designed so that there is no information advantage for the active observer --- as a result there is no corresponding performance advantage. In making decisions about the use of automation in complex systems, it appears that the critical issue for design is how the automation constrains the operators' access to information. If the automation enhances the information available to the operator, then the human-machine system should show improved situation awareness. However, if, as is generally the case, the automation distances the operator from critical information about the system, then the human's ability to detect failures and to respond adaptively to those failures will be compromised.

4.0 Depth Perception

The problem of depth perception combines interesting aspects of both contol of locomotion and of the difference between active and passive observers. Obviously, control of locomotion involves making judgments about the relative distances of objects in the field of view. Loomis, DaSilva, Fujita, & Fukusima, 1992) showed that performance in a distance judgment task varied as a function of the response mode. When passive, matching tasks were used, subjects showed systematic biases. These biases were consistent with the foreshortening that results when three-dimensions are projected onto a two-dimensional field using linear perspective. However, Loomis et al. and others (e.g., Thompson (1980; 1983) have shown that subjects show little error when blindly walking to a target in depth. Thus, different performance has resulted for active and passive observers. A series of studies was conducted in an attempt to better understand the factors that influence depth judgments. For complete details of the methodology and results see a Masters Thesis published at Wright State University (Robison, 1995).

4.1 Methodology

A series of experiments were conducted to study depth judgments. Two response modes were used. The first mode was pointing --- subjects made their responses using a laser pointer. The second mode was blind or ballistic walking --- subjects walked to the target with their eyes closed. Subjects were to match

standard distances that were indicated by markers on the ground. These standards could be either in the frontal plane or in the depth plane. The responses and standards could be either egocentric or exocentric. An egocentric distance was distance relative to the subject. An exocentric distance was distance relative to an arbitrary marker on the ground.

4.2 Results

The original hypothesis was that distance might be scaled in terms of an action metric. That is, that blind walking would generally yield accurate judgments. However, the results showed that accurate performance can be obtained for both walking and pointing response modes. The critical variable appeared to be the response frame. That is, whenever responses were made in terms of distance from the observer (egocentric), as opposed to distance between arbitary points on the gound (exocentric), accurate judgments of depth were obtained.

5.0 Minimally Invasive Surgery

Advances in video and imaging technology have made it possible for many surgeries to be accomplished using noninvasive techniques. These noninvasive techniques have many benefits for patients (e.g., less damage to healthy tissue, less scarring, and shorter recovery time). A cholecystectomy (gall bladder removal) typically involves 8 - 10 days in the hospital and 3 weeks to a month for full recovery when done using a traditional open procedure. However, when performed with a laparoscope, patients can return home as soon as 10 hours following surgery and can return to work within a few days. These benefits to patients, however, are purchased at the cost of far greater demands on the surgeon's perceptual and motor skills. With the laparoscope the perceptual-motor loop depends on a two-dimensional video image for feedback. Not only is the image 2-dimensional, but the normal eye-hand axis is replaced by the camera-hand axis. Typically, the camera will be oriented approximately 90° from the normal hand-eye axis. Thus, a movement from right-to-left with regard to the normal eye-hand axis will appear as a movement in depth on the video monitor. To make things more difficult, the camera is not fixed, but is moving under the control of an assisting surgeon. While the mobility of the camera allows the surgeon to look around and get the best perspective for each manipulation, the changing camera orientation creates a challenging and interesting problem for perceptual-motor coordination.

In order to understand the unique demands of laparoscopic surgery we have initiated two lines of research. The first line of research is a field study to identify the critical perceptual, motor, and cognitive demands that shape performance in surgery. The second line of research is a laboratory based program of experiments using a low fidelity simulation to evaluate the development of perceptual motor skills.

5.1 Field Studies

Over the past year we have been collaborating with physicians at the Wright State School of Medicine (Dr. Margaret Dunn) and at the Wright-Patterson Air Force Base Hospital (Dr. Daniel McKellar) to study the challenges associated with noninvasive surgery. These studies have included observations in surgery, participant observation in which two of my students and I received 4 hours of hands on training in laparoscopic surgery, and interviews with local surgeons. We are currently conducting structured interviews with expert (senior staff physicians with) and novice (senior residents with less surgical experience) surgeons using video from actual surgeries. Dr. Dan McKellar chose the videos and helped us to edit them down to an appropriate length and format for the interviews. The structured interviews are recorded on audio tape. Then they are transcribed and coded using the MacSHAPA software. (MacSHAPA is an exploratory data analysis tool for analyzing sequential data such as verbal protocols. It was developed by Dr. Penny Sanderson at the University of Illinois with support from the Armstrong Laboratory at WPAFB). At this date twenty interviews have been conducted (10 novices and 10 experts) and the transcription process is just beginning.

The transcripts from the interviews are being coded using categories derived from Rasmussen's work on cognitive systems engineering (e.g, Rasmussen, Pejtersen, & Goodstein, 1994). The coding system will look at the goal structures in terms of Rasmussen's abstraction hierarchy, the decision making activities in terms of Rasmussen's decision ladder, and the cognitive strategies employed by novices and experts. The primary objective of the verbal protocol analysis will be to identify differences in how experts and novices approach decision making in surgery. One hypothesis is that experts will show greater awareness of the hierarchical goal context as represented by the abstraction hierarchy. This should show up in the protocols as more references to higher-order constraints in terms of references to global goals and abstract functional constraints. In short, the experts will have a richer context for articulating "why" certain considerations are important. A second hypothesis is that experts will tend to rely on perceptual, recognition-based decision strategies and will tend to generate fewer, but better alternatives than novices. This hypothesis is consistent with work by Klein (1989) who has found that experts depend heavily on perceptual skills to identify alternative courses of actions. These experts tend to generate and evaluate single options, rather than to do comparisons across several options. Experts decision making might be characterized as narrow and deep, when compared to novices whose reasoning processes tend to be broader and more shallow. Such strategies are successful because experts are able to recognize and classify situations based on past experiences. We believe that these expert-novice distinctions may be a critical variable in understanding situation-awareness.

The long term goal for this project is to develop training protocols to accelerate the development of expertise. The nature of the training protocols will be contingent upon the results from the protocol analyses. The general plan is to integrate the video tapes used in the knowledge elicitation process with excerpts from the audio transcripts to illustrate the contextual scope and the perceptual distinctions that experts use in making decisions. The resulting training protocol will be evaluated using junior surgical residents in the Wright State Surgical Residency Program.

5.2 Laboratory Research

The laboratory research on laparoscopic surgery employs a low fidelity simulation that we have developed. The simulator illustrated in **Figure 8** requires subjects to pick up small plastic chips using an Endo-Babcock surgical instrument (this instrument is a racheting clamp used to grasp and manipulate tissue and organs during laparoscopic surgeries). The chips are picked-up from one container using the left instrument, then the chip must be transfered to the right instrument, and then deposited in a second container. To complete a trial 8 chips must be transfered. If a chip is dropped, then the subject must pick-up another chip from the container. The dependent measure is the time to complete the 8 transfers. An occluding screen prevents direct view of the workspace. Visual feedback is provided using a video camera and a standard video monitor. The simple arrangement makes it very simple to manipulate the position of the camera relative to the subject and the workspace.

This simulation was designed to replicate some of the perceptual-motor demands of surgery while at the same time being simple enough so that undergraduates with no surgical training can be used as subjects. Preliminary testing suggest that we were successful on both counts. The task has been tried by three different surgeons and a representative from a medical instrumentation company. The consensus of these experts is that the perceptual-motor demands are representative of the demands of surgery. We have also conducted a pilot test with a small group of undergraduates. These students showed initial frustration with the task, but were able to master the task over a period of about one week of practice for one hour per day. The subjects were to pick up and transfer 8 small plastic chips from one container to another. The transfer required that the object be picked up with the left instrument, passed to the right instrument, and then deposited in a container. Initial mean times were approximately 800 s. However, the subjects asymptoted at about 100 s by the end of the experiment.

The first experiment using this simulation will examine the relative importance of three relations within the perceptual-motor loop --- the relation between the hand and the camera, the relation between the hand and the work, and the relation between the camera and the work. A transfer paradigm will be used to assess the relative importance of the links. Three groups of subjects will be trained using the schematic setup illustrated in Figure 14. The camera will be

at the left hand. They will have to pick up objects from the left container and transfer them to the container on the right hand side. Each group will then transfer to one of the three arrangements illustrated in Figure 15. In the Transfer A condition, the position of the camera is moved (from the left hand to the right hand). With this change, the relation between the hand and the work remains invariant, but the relations between the hand and the camera and between the camera and the work are altered. In the Transfer B condition, both the camera and the work are moved so that the relation between the camera and the work is invariant, but the relations between the hand and the camera and between the hand and the work are altered (i.e., the chips must now be picked-up with the right hand and transfered to the left before being deposited in the left container). Finally, Transfer C, is designed to keep the relation between the hand and camera invariant while altering the relations between hand and work and between work and camera. This last condition is created by reversing the workspace without changing the position of the camera. Table 2 summarizes the relations for the three transfer condition. An equal sign (=) signifies a link that remains invariant and a not-equal sign (≠) signifies a link that is altered as a result of transfer.

TABLE 2

LINK	TRANSFER A	TRANSFER B	TRANSFER C
Hand/Work	=	≠	≠
Hand/Camera	≠	≠	=
Camera/Work	≠	=	≠

The transfer conditions were designed so that a different relation remains invariant in each transfer condition. This will allow us to assess the relative importance of each link. The assumption is that the size of the performance decrement upon transfer will be an index of the importance of the link. If a link is important, then there should be a large performance decrement when that link is altered, but little decrement when that link is invariant between training and transfer conditions. Pilot testing showed a large decrement for the Transfer B condition, but only a small decrement for the Transfer A condition. These results suggest that the link between the hand and work is important, because there was little decrement when this link remained invariant, but a large decrement when this link was altered. No data is available for the Transfer C condition.

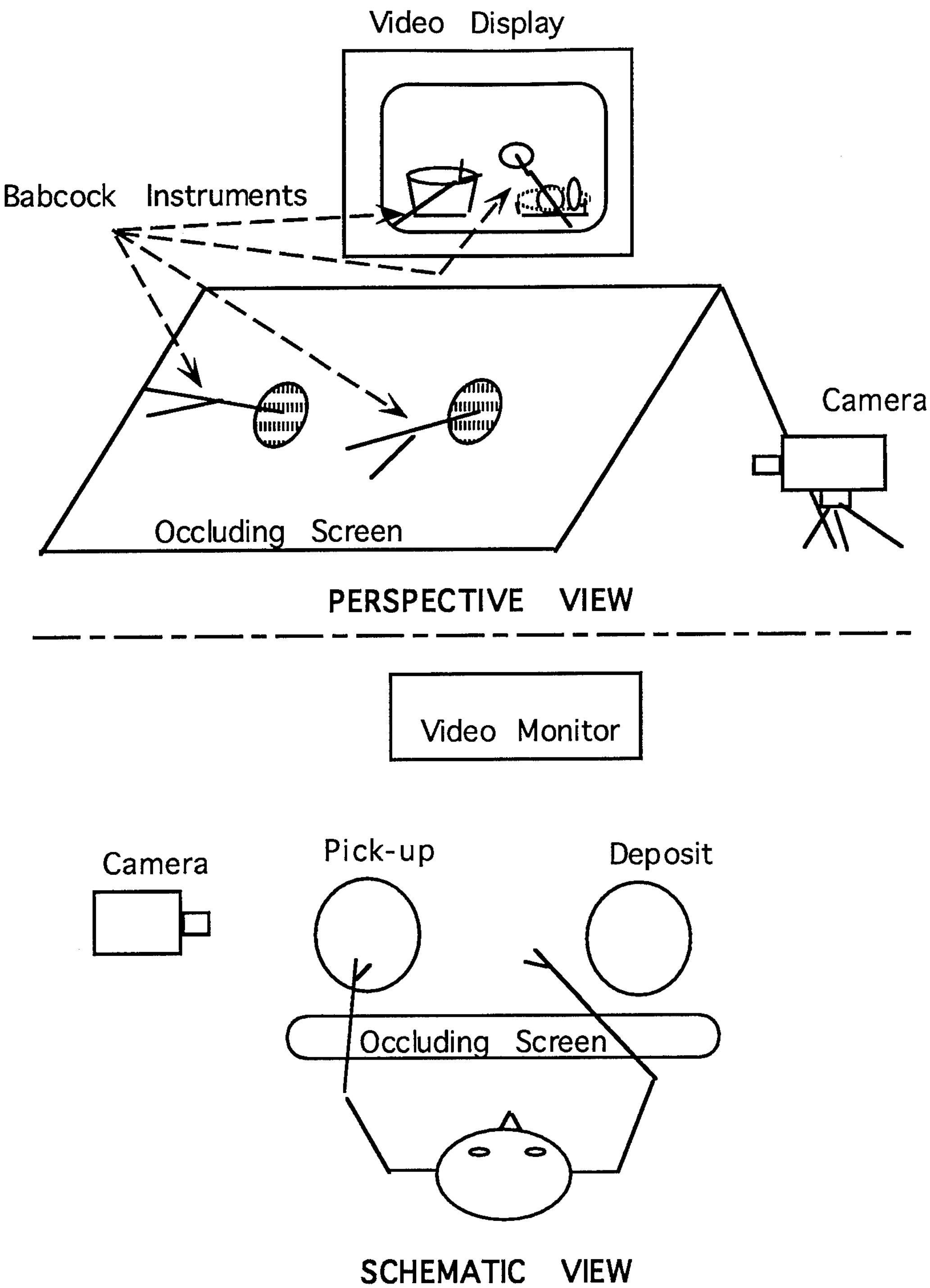

Figure 14. Perspective and schematic views of a low fidelity, laboratory simulation for studying the perceptual-motor demands of laparoscopic surgery. The subject's task is to pick-up plastic chips and to transfer them from one container to another using Endo-Babcock surgical instruments. Direct viewing of the workspace is occluded. Visual feedback is provided using a video camera and video monitor.

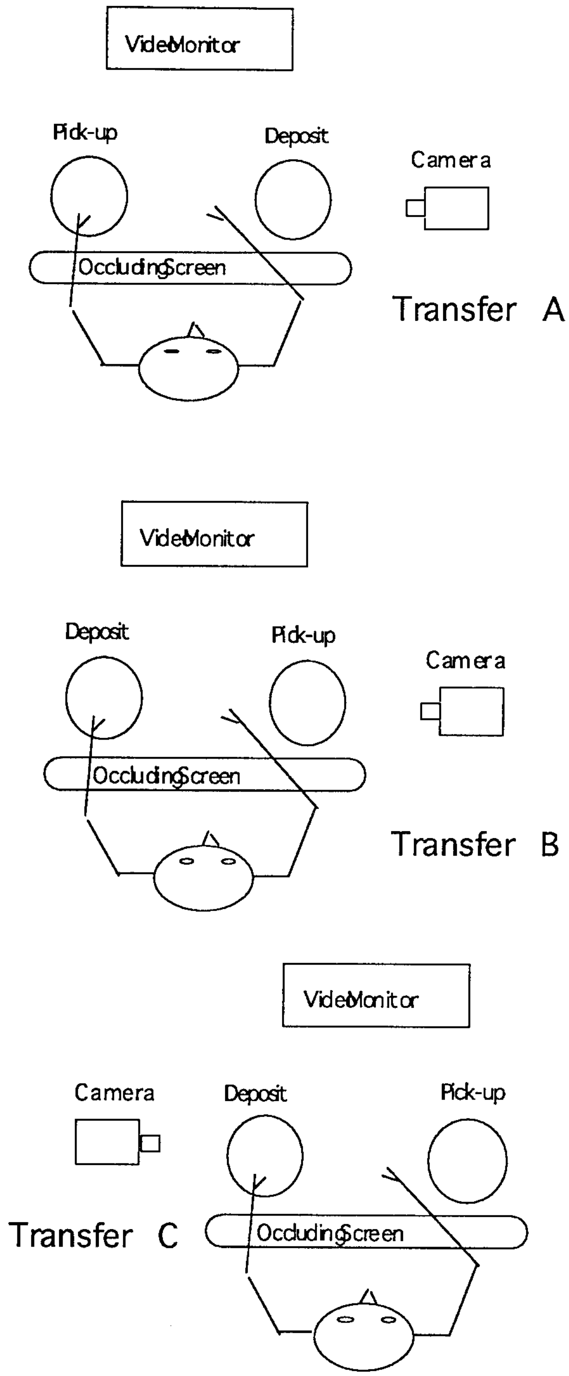

Figure 15. Schematic view showing three transfer conditions. Each transfer condition maintains a different invariant relation to the training condition shown in Figure 8. Transfer A maintains an invariant relation between the hands and the work. Transfer B maintains an invariant relation between the camera and the work. Transfer C maintains an invariant relation between the camera and the hands.

Experiments such as the one just described have important basic theoretical and practical implications. At a basic theoretical level, the question is how is the cognitive representation of space shaped by the constraints within the workspace. Which coordinates are preserved within the cognitive representation --- the intrinsic, egocentric body coordinates (right and left), the coordinates in the 2-D visual representation (i.e., video screen), the extrinsic coordinates of absolute 3-D space, or some higher order combination of these coordinate systems. The question is similar to the questions that have been addressed by Shepard and Metzler (1971) and Kosslyn, Ball & Reiser (1987) in thier classic work on visual imagery. The unique contribution of this work is that the questions are framed within an interactive, closed-loop, perceptual motor task, whereas much of the previous work has utilized noninteractive, perceptual judgment tasks. This work also has obvious links to research on adaptation to perceptual rearrangement (e.g., Welch, 1986) and mirror tracing.

In addition to the theoretical issues, this research has obvious implications for the design and utilization of simulators for surgical training. In designing low fidelity simulators, which links are most critical for ensuring postitive transfer to surgery? There is an interesting parallel between the questions currently being raised about the design of virtual reality systems for training advanced surgical procedures and questions that have been raised in the past about the design of flight simulators. The research on optical flow and the control of locomotion described earlier in this proposal was originally motivated by questions about the design of low fidelity visual flight simulators.

6.0 General Summary

This report describes four tracks of research that at a superficial level appear to be quite disparate. It is likely that some will view this as representative of a piecemeal and disjointed research program. Such a view highlights the differences between reductionistic and abstraction strategies of science. Reductionistic approaches achieve progress by studying narrowly defined problems in great depth. The abstraction strategy achieves progress by discovering invariants across different systems. The goal of the abstraction strategy is to relate the invariants to fundamental principles that will have broad generality. We believe that such a research program can have impact at both a basic science and an applied level.

We hope that it will be apparent to the careful reader that the problems of controling locomotion using information in optic flow, the question of active versus passive observers, the problem of depth perception, and the problem of manipulating surgical instruments based on feedback from fiber optic cameras are at an abstract level very similar. In each task domain, we are studying how the structure of information and the dynamics of action jointly constrain coordinated activity and situation awareness.

We believe that current interest in situation awareness reflects a growing awareness that the old reductionistic laboratory strategies based on stimulus-response models of causation are inadequate. Behavior in complex work environments reflects a coordination across a wide range of competing constraints. Basic research programs are needed that acknowledge and address this problem of coordination. In our program we are seeking to balance the demands for experimental rigor with the need for a holistic perspective that is responsive to challenges such as situation awareness that reflect the real constraints of compex, dynamic work environments.

In summary, beyond the specific questions of altitude judgment, dynamic occlusion, depth perception, and minimally invasive surgery, we believe that our program illustrates the power of attacking human performance as a control problem of coordinating perception and action. In our research program the independent variables have been constraints on information (e.g., available texture, observation mode, two-dimensional-video image) and constraints on action (e.g., ascent dynamics, response mode, laparoscopic instruments). Our tasks are designed so that we can measure the effects of these kinds of constraints on the coordination of perception and action. Where possible, we have attempted to keep the closed-loop coupling between perception and action intact. In generalizing to problems such as situation awareness, we believe that much progress can be made by modeling the information and action constraints of the task environment. These constraints constitute the behavioral field. As such, they shape the behavior of the organisms within that field. Our modeling efforts are directed at the properties of the field (e.g., the geometric analysis of the invariants associated with altitude) rather than at properties of the particles that inhabit the field.

7.0 Publication Activity

Masters Theses:

Allen, B. (1993). *Dynamic occlusion as information for object recognition: The effects of observer mode uncertainty*. Unpublished Master Thesis, Wright State University, Dayton, OH.

Brickman, B. (1994). *The effects of noise and temporally delayed sensory feedback on perception/action coupling.*. Unpublished Master Thesis, Wright State University, Dayton, OH.

Garness, S. (1995). *Global optical flow and altitude control: Resolving the signal-to-noise ratio hypothesis.*. Unpublished Master Thesis, Wright State University, Dayton, OH.

Hutton, R. (1993). *The role of activity in the perception of three dimensional objects from dynamic occlusion.*. Unpublished Master Thesis, Wright State University, Dayton, OH.

Kelly, L. (1993). *Altitude control and the interaction of global optical flow with ground texture type.*. Unpublished Master Thesis, Wright State University, Dayton, OH.

Robison, A. (1995). *Distance perception: A comparison of methods.*. Unpublished Master Thesis, Wright State University, Dayton, OH.

Journal Articles and Book Chapters:

Flach, J.M., Warren, R., Garness, S.A., Stanard, T., & Kelly, L. (Accepted pending revisions). Perception and control of altitude: Splay angle and depression angle. *Journal of Experimental Psychology: Human Perception & Performance.*

Flach, J.M. (In press). Beyond error: The language of coordination and stability. In J. Rasmussen & B. Brehmer (Eds.) *The Evolution and Breakdown of Adaptive Systems*. New Technologies and Work Series. New York: Wiley.

Flach, J.M. & Bennett, K.B. (In press). Methodological issues for evaluation of interfaces: A case for representative design. In R. Parasuraman & M. Mouloua (Eds.) *Automation and human performance: Theory and application.* Hillsdale, NJ: Erlbaum.

Flach, J.M. & Dominguez, C.O. (1995). Use centered design. *Ergonomics in Design*, July, 19 - 24.

Flach, J.M. (1995). Situation awareness: Proceed with caution. *Human Factors*, 37, 149 - 157.

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Flach, J.M. (1994). Situation awareness: The emperor's new clothes. In M. Mouloua & R. Parasuraman (Eds.) *Human performance in automated systems: Current research and trends.* (p. 241 - 248) Hillsdale, NJ: Erlbaum.

Flach, J.M. (1993). Active psychophysics: A psychophysical program for closed-loop systems. In E.J. Haug (Ed.). *Concurrent engineering tools and technologies for mechanical system design.* (p. 987 - 993). New York: Springer-Verlag.

Bennett, K. & Flach, J.M. (1992). Graphical Displays: Implications for divided attention, focused attention, and problem solving. *Human Factors,* 34(5), 513-533.

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Garness, S.A., Flach, J.M., Stanard, T. & Warren, R. (1994). The basis for the perception and control of altitude: Splay & depression angle components of optical flow. *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting.* (p. 1275 - 1279). Santa Monica: The Human Factors and Ergonomics Society.

Hutton, R.J.B., Flach, J.M., Brickman, B.J., Dominguez, C.O., Hettinger, L., Haas, M., & Russell, C. (1994). Keeping in touch: Kinesthetic-tactile information and fly-by-wire. *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting.* (p. 26 - 30). Santa Monica: The Human Factors and Ergonomics Society.

Flach, J.M. (1994). Beyond the servomechanism: Implications of closed-loop, adaptive couplings for modeling human-machine systems. *Proceedings of the '94 Symposium on Human Interaction with Complex Systems.* (p. 401 - 406). Greensboro, NC: Industrial Engineering Department, North Carolina A & T.

Kelly, L. Flach, J.M., Garness, S. & Warren, R. (1993). Altitude control: Effects of texture and global optical flow. *Proceedings of the Seventh International Symposium on Aviation Psychology*. Columbus, OH.

Flach, J.M. & Bennett, K.B. (1992). Graphical interfaces to complex systems: Separating the wheat from the chaff. *Proceedings of the Human Factors Society 36th Annual Meeting*. Santa Monica, CA: Human Factors Society. (pp. 470-474).

Flach, J.M. & Hancock, P.A. (1992). An ecological approach to human-machine systems. *Proceedings of the Human Factors Society 36th Annual Meeting*. Santa Monica, CA: Human Factors Society. (pp. 1056-1058).

Conference Presentations Publication of Abstract Only:

Flach, J.M. (1995). Putting the Human in Control: Toward Use-Centered Design. Invited Tutorial Session *Symposium on Human Interaction with Complex Systems*. Greensboro, NC: Department of Industrial Engineering, North Carolina A & T State University.

Flach, J.M. (1995). Cognitive Ergonomics of complex systems. Panel presentation *Symposium on Human Interaction with Complex Systems*. Greensboro, NC: Department of Industrial Engineering, North Carolina A & T State University.

Dominguez, C.O., Hutton, R.J.B., Flach, J.M., & McKellar, D.M. (1995). Human performance issues in video sugery. Presented at the *Aerospace Medical Association 66th Annual Scientific Meeting*. Anaheim, CA, (May).

Flach, J.M. (1995). Beyond the laboratory: Lessons from human factors. Invited paper presented at the*Sixty-Seventb Annual Meeting of the Midwestern Psychological Association*, Chicago, IL.

Brickman, B.J. & Flach, J.M. (1994). The effects of delayed sensory feedback on object recognition performance: Uncoupling perception and action. *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting*. (p. 954). Santa Monica: The Human Factors and Ergonomics Society.

Guisinger, M.A., Flach, J.M. & Robison, A.B. (1994). Fitts' law and the "force" or Newton: A match made in physics. *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting*. (p. 955). Santa Monica: The Human Factors and Ergonomics Society.

Robison, A.B., Hutton, R.J.B., & Flach, J.M. (1994). The role of action in perception. *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting*. (p. 955). Santa Monica: The Human Factors and Ergonomics Society.

Flach, J.M. (1993). Meaning a lost dimension. *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting*. (p. 1375 - 1376). Santa Monica, CA: The Human Factors and Ergonomics Society.

Flach, J.M. (1993). A constraint-based global perspective on information for control. Presented at the *VIIth International Conference on Event Perception and Action*. University of British Columbia, Vancouver, BC, Canada.

8.0 Participating Professionals

Graduate Students	RA Support	Thesis Completed
Brad Allen	8-90 - 9-91	1993
Bart Brickman	6-92 - 2-95	1994
Thomas Debris		
Cindy Dominguez	AFIT	
Sheila Garness	9-92 - 1-95	1995
Mark Guisinger		
Jay Holden		
Robert Hutton	6-92 - 2-95	1993
Leigh Kelly	9 -91 - 6-92	1993
Amy Robison		1995
Mathew Smith		
Terry Stanard	6-94 -	

Undergraduate Students: Jeffery Light; Patty Lake

9.0 Interactions

Presentations:

Flach, J.M. (1995). Information: Beyond the communications channel metaphor. Invited presentation to the Psychology Department, Rice University, Houston, TX.

Flach, J.M. (1995). Human factors challenges of minimally invasive surgery. Invited presentation to the Houston Chapter of the Human Factors and Ergonomics Society, Houston, TX.

Flach, J.M. (1995). Keep the horizon steady! The challenges of minimally invasive surgery. Invited presentation to the Tri-State Chapter of the Human Factors and Ergonomics Society. Cincinnati, OH (May 9).

Dominguez, C., Hutton, R., & Flach, J.M. (1994). Coordination of perception and action in video surgery. ERGO EXPO. Dayton, OH. (Sept 20)

Flach, J.M. (1994). Error in adaptive systems: Reconsidering fundamental assumptions about causality. Invited paper presented at the workshop on *Approaches to Modeling the Evolution and Breakdown of Adaptive Systems.* Annual Workshop on New Technologies and Work --- NeTWORK. Bad Homburg, Germany. (June 16 -18)

Flach, J.M. (1994). Going with the flow: Taoism, low altitude flight, and the meaning of life. Invited presentation at the Beckman Center, University of Illinois, Urbana, IL. (April 22)

Flach, J.M. (1994). Fitts' Law: Might the force be with it. Invited presentation to the Kineseology Department, University of Illinois, Urbana, IL. (April 22).

Flach, J.M. (1993). Beyond the servomechanism: Active Psychophysics. Invited presentation Risø National Laboratory, Kognitiv Systemsgruppe, Roskilde, Denmark. (Sept. 3)

Flach, J. M. (1993). Perception and action: A holistic approach. Presentation to the Center for Human Motor Research, Department of Movement Science - Division of Kinesiology, University of Michigan, Ann Arbor, MI. (March 26th).

Flach, J.M. (1993). Perception and Control in Low Altitude Flight. Presentation sponsored by the Purdue Student Chapter of the Human Factors and Ergonomics Society. Department of Industrial Engineering, Purdue University, West Lafayette, IN. (April 2nd).

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Flach, J.M. (1992). Perception/Action: A Holistic Approach. Presentation to the Human Movement Sciences Group, Psychology Department, The Free University, Amsterdam. (Dec).

Flach, J.M. (1992). Ecological approaches to design. Presentation to the Form Theory Group, Department of Industrial Design, Delft Technical University.

Flach, J.M. (1992). Human performance in low altitude flight. Invited lecture *The Tenth Annual International Conference on Aviation Physiology and Training: Human Factors in Aviation Part III*. Southampton, PA: Aeromedical Trianing Institute (AMTI) A Division of Environmental Tectronics Corporation.

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